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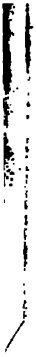

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LATE OF THE ROYAL MILITARY ACADEMY, WOOLWICH; AUTHOR OF "PRACTICAL PLANE GEOMETRY," "DESCRIPTIVE GEOMETRY," ETC., ETC.

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PREFACE TO VOL. II.

In the original edition of this work, published in a single volume at one shilling, so small a space could be afforded for the description of Optical Instruments, that it was necessarily very imperfect. In this new edition, in which a small volume is entirely devoted to the subject, much pains have been taken to produce a work, that, without pretending to rival the merits of more elaborate and expensive treatises, shall describe clearly the construction and use of the most important Optical Instruments, and the means of testing their merits.

The various mechanical modes of making copies of plans and drawings upon any desired scale, have been fully described in vol. i.; and the subject is completed in this volume by the introduction of a full description of the method employed in producing reduced copies of maps and plans by the assistance of photography, and in fixing the pictures produced by the camera, derived from the instructions of, and for the information of, engineer officers employed in the survey of India, which have been kindly forwarded to the author by Captain R. S. Palmer, R.E.

Valuable assistance has been received from several eminent opticians, and more especially from Messrs. Parkes and Son, of Birmingham, who supplied the author with many capital instruments for examination, and from Messrs. R. and J. Beck, who have furnished several of the illustrations, including that of the admirable first class microscope of their construction, which forms the frontispiece to this volume.

Watford,
1871.

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MR. J. F. HEATHER, M.A., late Mathematical Master at the Royal Military Academy, receives pupils, and undertakes their preparation for the Army, for the Indian Civil Engineering College, for the Civil Service, or for the Universities.

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from the instructions of, and for the information of, engineer officers employed on the survey in India, which have been kindly forwarded to me by Captain R. S. Palmer, R.E. Such other optical instruments as by their utility, or by the frequency with which they are brought before us, appear to demand attention, will also meet with due consideration.

CHAPTER I.

PLANE AND CURVILINEAR REFLECTORS. THE KALEIDOSCOPE.

PLANE REFLECTORS.

A COLLECTION of straight lines, either conical or cylindrical, representing rays of light, is called a *pencil* of light, and

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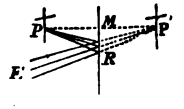
the axis of the cylinder or cone is called the *axis* of the pencil.

The term *medium* is used in optics to signify any *transparent* substance, that is, any substance through which a portion of the light falling upon it can pass.

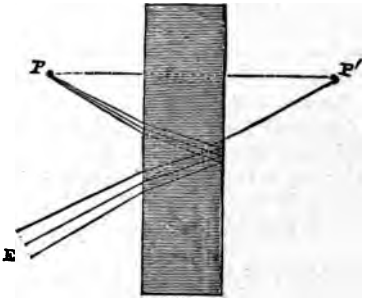
When a ray of light is reflected at a plane surface, the reflection takes place in a plane perpendicular to the reflecting surface, and the incident and reflected rays make equal angles with this surface. Thus, if Q A represent a ray of light incident upon a plane reflector at the point A, and the plane of the paper represent the plane which contains Q A, and is perpendicular to the reflecting surface, intersecting it in the line R A R′, then, making the angle Q′ A R′ equal to the angle Q A R, and in the same plane with it, A Q′ will represent the course of the reflected ray.

The effect of a plane reflector upon the pencils of light which fall upon it is to change the direction of all the rays forming each pencil, without altering the angles at which the several rays of the pencil are inclined to one another, so that the divergency or convergency of the pencils remains the same after reflection as before, and the objects from which they proceed appear to be at the same distances behind the mirror as they really are in front of it. Thus, a pencil of light diverging from a point of an object at P, after reflection at the point R of a plane mirror, appears to proceed from the point P′ on the line P M P′, perpendicular to the mirror, at the distance M P′ behind the mirror equal to the distance M P. The point P′, from which, after reflection, the pencil appears to have diverged, is called a virtual focus; and the apparent image of the object behind the mirror is called a virtual image.



Reflection from two Parallel Plane Surfaces.—When an object is placed between two plane reflectors, the rays proceeding from the object and falling upon one of these reflecting surfaces, are turned back, and fall upon the second surface: from this they are reflected back again to the first, and so on alternately, forming an endless series of images behind the mirrors. In like manner, the rays falling first upon the second mirror form a second endless series of images. These images, however, grow fainter and fainter, and thus gradually

iway, until they are no longer bright enough to render iselves visible. By colouring an object red on one side blue on the other, the series of images, which results from reflected first from one of the mirrors, can readily be distinhed from that which results from a first reflection at the r. Plane reflectors are usually made of glass plates, well hed, on both faces and coated with metal, or, as it is called, red, on one of these faces. In this manner a highly hed plane metallic surface is obtained, the brilliancy of h is effectively preserved by the glass covering. The of light which pass through the medium of the atmore and fall obliquely on the surface of the glass, are bent, fracted, on entering the denser medium of the glass, are reflected at the metallic surface at the back of the glass, are again refracted upon emerging from the glass into the



sphere. The distance behind the mirror of the apparent e, formed by the combination of the refractions with the ction at the metallic surface, varies with the position of eye, being greatest when the eye is as nearly as possible e same line with the object and its image, without the r being hidden by the former. This greatest distance of pparent image behind the mirror is equal to the distance e object in front of the mirror together with four-thirds hickness of the glass. If then the object be placed in ediate contact with the glass, the distance between the t and its image, when viewed as directly as possible, is thirds the thickness of the glass; and, conversely, *the ness of the glass is three-fourths the distance between the and its apparent image.*

The light, however, proceeding from the object does not all pass through the glass to the metallic surface at its back; a portion of it is reflected from the first surface without entering the glass at all: neither do the rays reflected from the metallic surface all pass out again after recrossing the thickness of the glass; a portion are again reflected internally back to the metallic surface, again reflected there, and again in part emerge, and in part are again reflected, thus forming a series of apparent images, growing fainter and fainter, and, in fact, so far exceeded in brightness by the apparent image formed at their first meeting with the metallic surface, as in general to be entirely eclipsed by it. By placing, however, a lighted candle before an unsilvered glass in front of a dark background, the series of images may be easily seen. It follows, therefore, that when a pencil light falls on a glass surface, it does not all pass through it; but a portion is reflected back from each surface of the glass, and a portion lost for all practical purposes by a series of internal reflections.

The plane reflector, formed of polished glass with silvered back, is universally employed as an article of domestic furniture, under the name of a *looking-glass*.

The test of a good looking-glass is the non-distortion of distant objects looked at very obliquely.

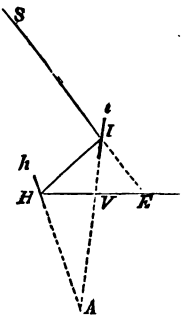
The formation of a true plane surface is by no means an easy problem, and in the plane reflector we must have not only one, but two, true planes, and they must, moreover, be strictly parallel.

The more highly polished the surfaces are, the brighter will be the images formed; and the mirrors which look the darkest are generally the best.

REFLECTION FROM TWO INCLINED PLANE SURFACES.

When a ray of light, proceeding in a plane at right angles to each of two plane mirrors, which are inclined to each other at any angle whatever, is successively reflected at the plane surfaces of each of the mirrors, the total deviation of the ray is double the angle of inclination of the mirrors. For let I *i* and H *h* represent sections of the two mirrors made by the plane of incidence at right angles to each of them, and let S I represent the course of the incident ray: then the ray S I is reflected at I into the direction I H, making with I *i* the angle H I A, equal to the angle S I *i*, and is again reflected at H into the direction H E, making, with H *h*, the angle E H A

equal to the angle I H *h*. Now the angle A H V, being equal to the exterior angle I H *h*, is also equal to the two interior angles H I A and H A I; and because the vertical angles A V H and I V E are equal, and that the three angles of every triangle are equal to two right angles, therefore the two angles V I E and S E H are, together, equal to the two angles A H V and H A I, and therefore to the angle H I A and twice the angle H A I (since A H V has been proved equal to H I A and H A I); but V I E, being equal to the vertical angle S I *i*, is also equal to the angle H I A: therefore, taking away these equals, the remainder, the angle S E H, is equal to the remainder, twice the angle H A I. *Q.E.D.*

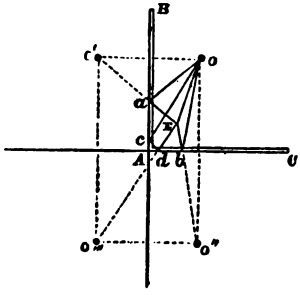


This property of two plane reflectors enables us by their aid to measure the angle subtended at the eye by any two objects whatever, and is the foundation of the construction of Hadley's Quadrant, and the improvements upon it, in Hadley's Sextant, hereafter to be described.

THE KALEIDOSCOPE.

Repeated Reflection at Inclined Mirrors.—When an object is placed between two plane mirrors which are inclined to one another at an angle, a limited number of images are formed, arranged in a circular form round the intersection of the two mirrors; and, by properly choosing the angle of inclination, very interesting and beautiful effects are produced. Let us take, for instance, two mirrors, A B and A C, at right angles to each other, and let o represent an object placed between them; then the rays of light diverging from o, which fall upon the mirror A B, will, after reflection from this mirror, diverge from the point o′, at the same distance behind A B, that o is before it; again, the rays from o that fall on A C will, after reflection, diverge from o″, at the same distance behind A C that o is before it; and, lastly, rays which, after reflection at A B, fall upon A C, will then diverge from o‴, at the same distance behind A C that o′ is before it; and, in the same manner, rays proceeding from o, first to A C, and then reflected to A B, will again be reflected from this mirror, and appear to proceed from o‴. The point o‴ being

behind both mirrors, the rays diverging from it can be no more reflected, and hence there will be three images, o′, o″, o‴, of the object o, and no more, formed by reflection at the two mirrors, and they manifestly lie on the circumference of the circle described from A, at the distance A o. Now, a ray o*a*, proceeding from o, is reflected in the direction *a*E, as though proceeding from o′, a ray o*b* is reflected in the direction *b*E, as though proceeding from o″, and a ray o*c* is reflected first into the direction *cd*, and then into the direction *d*E, as though proceeding from o‴, and thus an eye placed opposite to the point E, and looking along the intersection of the two mirrors, will see at the same time the object o and its three images, o′, o″, and o‴.



Symmetry.—Since the image of each point of an object is at the same distance behind a plane mirror as the point itself is before it, it follows that, however irregular the form of an object may be, this object, together with its image, produce a figure perfectly symmetrical with respect to the reflecting surface. Again, we have seen in the case of two mirrors, at right angles, that the images o‴, formed by reflection first at one mirror and then at the other, coincide; and this coincidence of the last images formed will always occur, whenever the number of degrees in the angle of inclination of the two mirrors is an even divisor of 360°; consequently we shall have then a number of pairs of images, forming a series of symmetrical figures symmetrically arranged round the intersection of the two mirrors.

Construction of the Kaleidoscope.—This property of the symmetrical arrangement of the figures produced by the reflections, is taken advantage of in the construction of the instrument invented by Sir D. Brewster, and named the *kaleidoscope.* Two plane mirrors, A B, A C, formed of slips of glass silvered at the back, are placed in a tube, A B C, blackened on the inside, and set at an angle of 60°; at one end of the tube are then fixed two discs of glass, between which any such objects as pieces of coloured glass, petals of

flowers, beads, &c., can be placed; and by shaking or turning round the tube, fresh combinations of some of these objects are continually brought between the two reflecting surfaces, and thus present to an eye looking through a hole in an opaque disc at the other end of the tube, an endless variety of beautifully symmetrical figures. Thus, an object with the irregular outline *a b c d* would present the three similar symmetrical forms, of which *d c b a d' b' c' d'* is one, represented in Fig. 1, the whole series being symmetrically

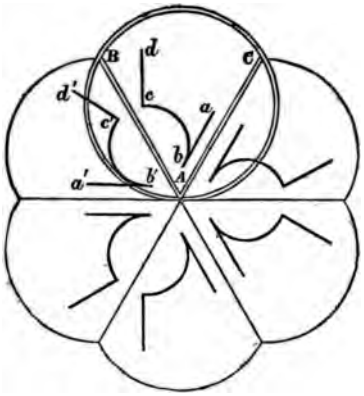


Fig. 1.

arranged with respect to each of the three diameters of the hexagonal diagram.

Fig. 2 shows the effect that would be produced by the same object, if the two mirrors were at right angles: the symmetry would still be perfect; but from the paucity in the number of the symmetrical figures produced, the effect would be inferior to that produced by an inclination of 60°. With an inclination of 45° four symmetrical figures would be produced; with one of 36°, five, and with any smaller inclination, which should be an *even* divisor of 360°, still more symmetrical combinations would appear; but the diminished light at each successive reflection detracts from the effect produced; so that the inclination of 60° has been found to give the best effect.

When the number of degrees in the angle of inclination is

an *odd* divisor of 360, the symmetry is no longer perfect, and the images of different portions of the object may ultimately

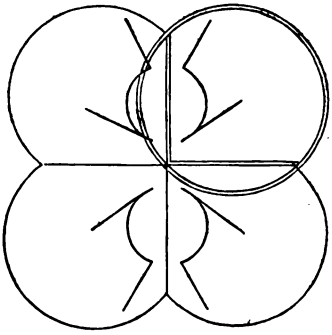


Fig. 2.

overlie each other. Figs. 3 and 4 represent the effects produced by inclinations of 120° and 72° respectively.

If the number of degrees in the angle were not an exact divisor at all of 360°, still greater confusion would be produced.

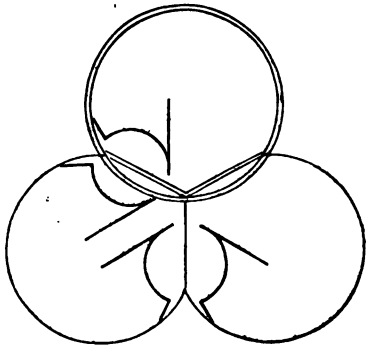


Fig. 3.

By placing a third reflector in the tube, so as to form with the two others a hollow equilateral prism, an additional

number of symmetrical combinations will be produced, and,

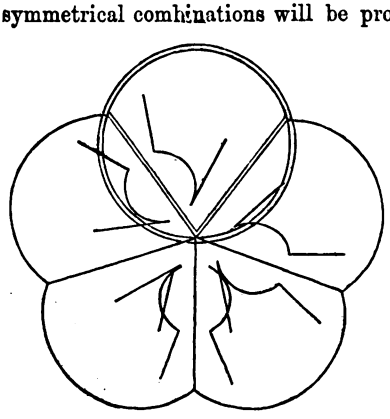


Fig. 4.

in fact, will be repeated, like the images in parallel mirrors, becoming fainter and fainter, until lost in obscurity.

ON CURVILINEAR REFLECTORS.

Spherical reflectors, or specula, as they are called, produce upon pencils of rays results precisely similar, with one exception, to those produced by lenses (p. 19). Thus, a *concave reflector* makes the rays of the pencils incident upon it more convergent, and corresponds in its uses with a convex lens; while a *convex reflector* makes the rays of the incident pencils more divergent after reflection, and corresponds in its uses with a concave lens. The exception to the similarity of the results produced by lenses and reflectors is, that with the latter there is no chromatic dispersion (p. 21), and the only sources of error are the aberration and spherical confusion, which are common to both spherical reflectors and lenses. For astronomical observations, however, in which case the rays incident upon the object-speculum are parallel, these sources of error are removed by making this speculum of a parabolic form, and another speculum, if it be used, of the form of the vertex of a prolate spheroid. There is great difficulty in procuring flint glass in pieces of large size without flaws, and we are consequently limited as to the size of the lenses of good quality that can be formed with such glass; and, without its use, we

have not hitherto been able to form available achromatic object-glasses. Recourse is, therefore, had to parabolic or spherical specula in the formation of telescopes of large power for examining the heavens.* These specula are formed of metal, and the chief objection to them is the impossibility of producing an accurate surface. Even supposing its general form to be correct, there are always minute inequalities arising from the nature of the substance, which cause a waste or dispersion of light. Great pains are, consequently, taken in their construction to obtain the form and surface of the best possible quality.†

* Sir William Herschel's largest telescope was 40 feet long, and the mirror 4 feet wide. Lord Rosse's largest telescope is 56 feet long, and the mirror 6 feet wide.

† The following description of the methods employed in forming and polishing parabolic reflectors is extracted in an abridged form from an account of Skerryvore Lighthouse, by Alan Stevenson, LL.B., F.R.S.E., M.I.C.E., Engineer of the Northern Light Board:—

"The reflector plate is formed of Virgin silver and the purest copper, from the ingot, in the proportion of 6 oz. silver to 16 oz. of copper. The two metals are formed into pieces of the form of rectangular parallelopipeds about 3 inches in length, and the same in breadth, and are then tied together with wire, placed in the furnace, and united with a flux of burnt borax and nitre, mixed to the consistence of cream. The metal thus united is repeatedly passed through the rolling mill, and annealed in the furnace after each time of passing through, until it comes out a plate 28 inches square. It is then cut into a circular disc ready for hammering; and great care must be taken to keep the metal clean during the process of hammering and polishing now to be performed.

"The hammering is commenced by placing the plate with the copper side upon a block slightly concave, and beating it on the inner or silver side with a box-wood mallet, rounded at each end, *c* and *d* (Fig. 1). The beating is commenced on the edge and continued round and round till the centre is gradually reached. After the disc has been raised sufficiently by this means, it is taken to a machine called the horse, and beaten with a wooden mallet upon the copper side, its concave face being turned about upon a bright steel head *a* (Fig. 2), until it has nearly reached the proper height for the reflector, which is ascertained by a mould *m* (Fig. 3).

"After each course of raising with the wooden mallet the reflector is annealed, as follows: first damped with clean water, and dusted over with powder, composed of one pint of powdered charcoal to one ounce of saltpetre; then put on a clear charcoal fire, till the powder flies off and shows when it is duly heated. It is next plunged into a pickle, composed of one quart of vitriol, in five or six gallons of water; and, lastly, washed with clean water and scoured with Calais sand.

"The next step is to put the reflector into an iron stool, and, having drilled a small hole in its vertex, to describe a circle from this point with beam compasses, and cut the paraboloid to the proposed size.

"The reflector is now *hard-hammered* with a planishing hammer, or planished, as it is called, on the bright steel head *a*; and then *smoothed* with a lighter hammer muffled with parchment. Then comes

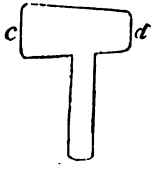


Fig. 1.

Fig. 2.

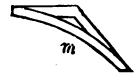


Fig. 3.

the finishing, called also filling up to the mould, which is thus performed. It is constantly tried with the mould *m*, and those portions which do not meet it are marked with fine slate pencil, and then gone over with the muffled hammer, till every point touches the mould. Great care must be taken in this process that no part of the surface be raised above the gauge, or the reflector would have to be reformed with the wooden mallet, and the whole process repeated. The reflector is then tried with a lamp brought to its focus, and, if the whole surface is luminous, it is fit for polishing; but, if not, it must be again tested by the mould, and carefully filled up with the muffled hammer, till the result of the lamp test is perfectly satisfactory.

"The edge of the reflector is next turned over to stiffen it, and the bizzle *w* (Fig. 1), and back belt *g* (Fig. 2), having been soldered on, the final process of polishing may be proceeded with. This process is commenced by scouring, first with a piece of pure charcoal of hard wood, and next with a mixture of Florence oil and finely-washed

Fig. 1.

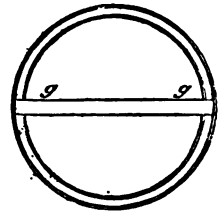


Fig. 2.

rotten stone, applied by means of a large ball of superfine cloth. The reflector is then cleansed with a fine flannel dipped in Florence oil, and afterwards dusted over with powder of well-washed whiting, and wiped out with a soft cotton cloth. Lastly, it is carefully rubbed by the naked hand with finely washed rouge and clean water, and wiped with a smooth chamois skin. In all the polishing and cleansing processes some skill is required in the manipulation, as the hand must be moved in successive circles parallel to the lips of the reflector, and having their centres on the axis of the generating curve."

The speculum of Lord Rosse's great telescope is composed of 1264 parts of copper and 589 of tin, fused together and cast in a mould, the bottom of which is formed of hoop iron bound closely together with the edges uppermost. By this means the heat is conducted away through the bottom so as to cool the metal towards the top, while the interstices between the hoops, though small enough to prevent the metal from running out, are sufficiently open to allow the air to escape. After casting, the speculum is annealed in a brick oven, which is heated almost to a red heat, and shut up with the speculum in it, and allowed to cool gradually. The speculum is then placed with its face upwards upon a turning apparatus, and the grinding and polishing performed entirely by the aid of mechanical contrivances, so that the proper parabolic form is accurately given to it. To test the work, the dial plate of a watch is placed upon the top of a mast at 90 feet distance from the speculum, and the image of this dial-plate formed by the speculum, being viewed through an eye-glass properly placed, the distinctness of this image denotes the accuracy of the speculum.

CHAPTER II.

PRISMS. THE CAMERA LUCIDA.

THE PRISM.

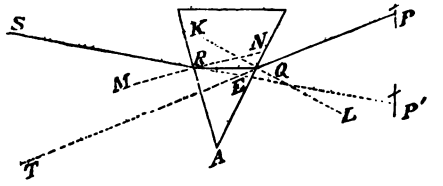
THE term *prism* in optics is used to signify a portion of any medium bounded by plane surfaces which are inclined to one another. The bounding surfaces are called the *faces* of the prism; the line in which the faces intersect is called the *edge* of the prism; and the angle formed by any two adjoining faces through which the pencil of light passes is called the *refracting angle*.

The prism is to be placed so that the axis of the pencil, by which an object is seen through it, may be in a plane perpendicular to the edge of the prism, and during and after its passage through the prism still remain in this plane.

One effect of a prism of denser material than the surrounding medium is to bend every ray of light passing through it, and, consequently, the whole pencil, further from the refracting edge of the prism.

Another effect of such a prism is to decompose each single ray of white light into several rays of different colours, which rays are bent at different angles, so as to form a lengthened image of different colours, of the point from which the ray proceeds. This image is called the spectrum, and these colours the colours of the spectrum.

When, then, any object is viewed through a prism, the two following effects are produced. 1stly. The apparent position of the object is changed, so that, if the prism be held with its edge downwards, as in the accompanying figure, the



object appears lower than it really is, while, if the prism were held with its edge upwards, the object would appear in a position higher than its actual position. 2ndly. The boundaries of the object are indistinctly defined, and fringed with colours.

The figure represents the section of the prism made by the plane of incidence, that is, by the plane which is perpendicular to the edge of the prism, and contains the incident ray of light P Q, forming the axis of the pencil under consideration, which proceeds from one point of an object P. A Q and A R are sections of the faces of the prism; A is a point in its edge; and the angle Q A R is its refracting angle. Now the ray of light P Q, proceeding from the object at P through the medium of the atmosphere, is bent, upon entering the denser medium of the prism, from the direction Q T into the direction Q R, nearer to L Q K, the perpendicular, to the face A Q of the prism, at the point of incidence Q; and, upon emerging from the prism into the rarer medium of the atmosphere, is again bent from the direction Q R into the direction R S, further from M R N, the perpendicular to the face A R at the point of emergence R. The eye, being placed at S, sees the point P, therefore, by means of a pencil of light of which S R is the axis, and P consequently appears at P' on the prolongation of the line S R. A similar effect being produced upon every other point, the entire object is apparently depressed, as represented in the figure.

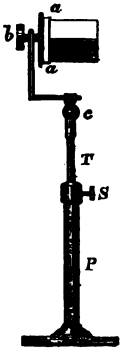
The angle T E S, or P E P', between E R S, the direction of emergence, and P E T, the direction of incidence, is called the angle of deviation.

The amount of refraction, when a ray of light passes from one medium into another, varies with the angle of incidence, so that the sine of the angle of refraction bears a constant ratio to the sine of the angle of incidence. This ratio varies for each different medium, and is called the refracting power of the medium. The deviation of a ray in passing through a prism varies also with the angle of incidence, and has a minimum value when the angles of incidence and emergence are equal. The refracting power can be determined by finding practically this minimum deviation, as follows:—Place the prism with its edge downwards, so as to receive a small beam of solar light, admitted into a dark room through a hole in a shutter, and let the beam of light, after refraction, be received upon a screen behind the prism. The prism must then be turned round an axis parallel to its edge, so as to vary the angle of incidence, and, consequently, the position of the bright spot upon the screen; and, in one particular position, we shall find the bright spot to remain stationary for an instant, though the motion of the prism is continued. The deviation will then be a minimum, and will be equal to the sum of the sun's altitude and the inclination of the emergent beam to the horizon. Let s represent this minimum deviation, and A the refracting angle of the prism, and let the refracting power be represented by μ: then $\mu = \dfrac{\sin. \frac{A+s}{2}}{\sin. \frac{A}{2}}$

Since a ray of light emerging from a prism into the rarer medium of the atmosphere is bent farther from the perpendicular to the emergent face of the prism, it follows that the angle of incidence on this face may be increased until the angle of emergence becomes a right angle, and the emergent ray is consequently parallel to the face of the prism. If then the angle of incidence be still further increased, the ray cannot emerge at all at this face, but is totally reflected within the prism. The angle of total reflection for glass is about 41°, and hence, when a ray passing into a glass prism falls on the emergent face at an angle with the perpendicular to this face, exceeding 41°, it is totally reflected.

The consideration of the properties of the prism is of great importance, as exhibiting in the simplest manner the principles of the refraction and dispersion of light.

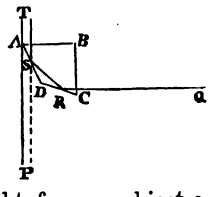
For the purpose of examining these properties, the prism is usually mounted on a stand, similar to that represented in the annexed figure. This stand consists of a hollow pillar, P, in which slides a tube, T. This tube is fixed at any desired height by a tightening screw, S; and to it the frame carrying the prism is attached by a knuckle-joint, C. The prism is attached to the piece *a a*, which has an axis passing through the upright portion of the frame, and can be turned round by the milled head *b*. It will thus be seen that the apparatus can be adjusted so as to place the prism in any desired position whatever with respect to the incident light.



Plane reflectors were formerly used in mathematical instruments to change the directions of pencils of light, whenever such a change was necessary or desirable; but in all cases in which the deviation, or amount of the change, is constant, prisms have now superseded the use of the plane reflector. The prisms are made of such a form that the immergent and emergent faces are perpendicular respectively to the incident and emergent rays, and thus the loss of light from reflection at these surfaces is rendered as small as possible while the faces upon which rays fall within the prism at angles less than the angle of total reflection (p. 14) form the most perfect reflectors that can be obtained.

HE CAMERA LUCIDA.

This ingenious instrument, the invention of Dr. Wollaston, consists of a quadrilateral prism, of which A B C D represents a section made by a plane at right angles to each of its edges: A B is equal to B C, and A D to D C, and the angles of the prism are a right angle at B, an angle of 135° at D, and angles each 67° 30′ at A and C. Over the face B A, and projecting beyond A, is a plate of metal having in it a narrow longitudinal aperture, which is just bisected by the edge A of the prism.

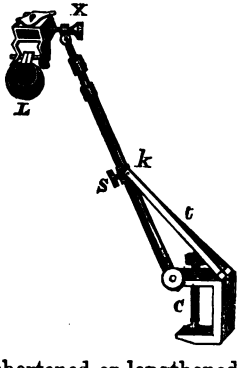


The axis, Q R, of a small pencil of light from an object Q, directly in front of the face B C, passes straight through this face, and falls upon the face D C, making with it an angle of

22° 30′. It is there reflected into the direction R S, and falling upon the face D A, at the same angle, is again reflected into the direction S T, perpendicular to the face A B, and consequently passes straight through this face without refraction. Looking down through the aperture in the metal plate, an image of the object Q is seen at P, at a distance from A B equal to the distance of the object itself from B C; and if A B be placed at a distance from a table not less than the distance of distinct vision, and a sheet of paper be laid upon the table at P, the image of the object, as seen through the prism, will be thrown upon the paper, seen through the projecting part of the aperture, and an accurate drawing of the object may be traced upon the paper.

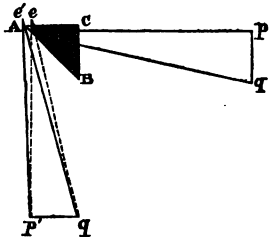
It is necessary, for distinct vision of both the object and the drawing at the same time, that the pencils of rays proceeding from them should have nearly the same degree of divergence. This is accomplished by placing the prism, as above directed, at a distance from the table not less than the distance of distinct vision, when such an arrangement is possible; but when such an arrangement is impossible, or inconvenient, a lens may be placed between the table and the prism. To adapt the instrument for use without fatiguing the eye, coloured glasses should be used, to give nearly the same brightness to the two images.

To effect the arrangements described above, the prism is mounted upon an axle, X, parallel to its edges. This axle is attached to the end of a rod sliding in a tube which has at the other end a clamp, C, for fixing it to the edge of the table. The tube is connected with the clamp by a knuckle-joint, and the setting piece *t*, is also jointed to the clamp at one end, and at the other to a collar, *k*, through which the tube can slide, and be fixed at any desired inclination by the screw *s*; and, by sliding the rod that holds the prism in or out of the tube, the distance of the prism from the table may be shortened or lengthened at pleasure.



Lenses and coloured glasses are mounted at L upon an axis below the prism.

The purpose accomplished by the two reflections, first at the face C D, and then at the face D A of the prism, is to render the image of the object erect, otherwise an inverted image,

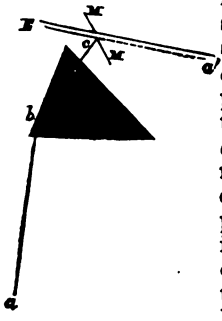


q' p', of the object p q, might be formed by a single reflection at the face A B of a rectangular prism, A C B.

Whatever be the form of the prism, however, the eye must be kept steadily in such a position that the pupil is bisected, or very nearly so, by the edge A of the prism. For let p q represent an object in face of the prism, and p' q' its image in apparent coincidence with the paper on the table: then, drawing the lines p' A e and q' A e', from the points p' and q', through the edge of the prism, to meet the pupil of the eye in the points e and e', it is manifest that no ray from the point p of the object can be reflected to the left of the point e, nor can any ray from the point q' of the paper reach the eye to the right of the point e'. If, therefore, the eye be so far advanced over the prism that the point e' falls below the pupil, a portion of the paper at the bottom of the image will be invisible, and if the eye be drawn back until the point e fall above the pupil, a portion of the image at its upper part, p' will be invisible. Hence, to obtain distinct vision at the same time of the entire image, and of the paper on which it is projected, the eye must be so placed that the limiting reflected ray p' e from the object shall pass below the upper edge of the pupil, and the limiting direct ray q' e' from the paper in coincidence with the image shall pass above the lower edge of the pupil. To make this possible, the distance between the points e and e' must be less than the diameter of the pupil. Again, the entire diameter of the pupil being usually about one-fifth of an inch, it follows that a very slight

motion of the head will serve to put out of view a portion either of the image or of the paper in coincidence with it. A considerable amount, then, of practice and patience will be needed in order to become expert in the use of this instrument.

There is another form of the camera lucida, in which an image of the hand and paper is seen by reflection, and the object is looked at through a small hole about the eighth of an inch in diameter. To render the image erect, the rays may first be reflected at the interior surface of a prism, and then at the surface of the plane reflector M M: thus, *a b c* E represents the course of a ray proceeding from the paper in the direction *a b*, and reflected first from the point *b* of the prism to the point *c* of the mirror, and thence from the mirror to the eye at E; while the rays from the object pass to the eye directly through the hole in the mirror M M. This is the form of the instrument used by Amici with the microscope; and, as the image of the hand and paper is certain to be reflected to the eye from some portion of the reflector, it is only necessary to direct the sight through the aperture so as to obtain a full view of the object; and thus the difficulty experienced in adjusting the position of the eye, when using the Wollaston form of the instrument, is in this form obviated.



CHAPTER III.

LENSES AND SPECTACLES.

LENSES.

A PORTION of any medium bounded by two spherical surfaces having a common axis, or by a spherical surface and a plane one, is called a *lens*.

The effects produced by lenses upon pencils of light depend both upon the form of the lens itself, and upon the

direction in which the pencil is proceeding with respect to the lens. Lenses consequently receive distinguishing names, to mark either different forms, or different positions with respect to the light falling upon them. These distinguishing names are the following, and the forms and positions of the corresponding lenses are represented in the accompanying diagram, the light being considered to be proceeding from left to right:—

1. Convex meniscus.
2. Concave meniscus.
3. Double convex.
4. Double concave.
5. Plano-convex.
6. Convexo-plane.
7. Plano-concave.
8. Concavo-plane.
9. Concavo-convex.
10. Convexo-concave.

The rays forming any pencil of light must either be divergent, parallel, or convergent; and when a pencil of light passes through an essentially convex lens, that is, one which is thicker in the middle than at the edges, as 1, 2, 3, 5, 6, the rays are made more convergent, so that a pencil of converging rays becomes still more convergent, a pencil of parallel rays becomes convergent, and a pencil of diverging rays becomes either less divergent, parallel, or convergent: but when a pencil of light passes through an essentially concave lens, that is, one which is thinner in the middle than at the edges, as 4, 7, 8, 9, 10, the rays are made more divergent, so that a pencil of converging rays becomes either less convergent, parallel, or divergent, a pencil of parallel rays becomes divergent, and a pencil of diverging rays becomes still more divergent.

The sensation of vision is produced by pencils of rays proceeding from every point of the visible object, and entering the pupil of the eye; and in order to produce distinct vision the rays of each such pencil must either be parallel or slightly divergent. Thus the sun, moon, and planets are seen distinctly, although so distant, by parallel rays; and the least distance from the eye at which an object can be seen distinctly varies in different persons, according to the power of the natural lenses which, in fact, form the eye. 1. When any object is brought nearer to the eye than this without the inter-

vention of a lens, the vision becomes confused. If, however, the rays of light proceeding from the object were, by the interposition of a convex lens, rendered less divergent or parallel, the vision would be again distinct. 2. It is further necessary for distinct vision that the intensity of the light be not less than a certain intensity, as may easily be exemplified by gradually closing the shutters of a room, and thus diminishing the intensity of the light proceeding from the objects in the room, when they will grow more and more indistinct. 3. Lastly, it is also necessary, for distinct vision of any object, that the axes of the pencils proceeding from its extreme parts enter the eye under an angle not less than a certain angle, so that, however strong a light be thrown upon an object, if this object be very minute, or removed to a distance very great with respect to its magnitude, it will not be seen by the naked eye. If, however, by the assistance of a lens, or combination of lenses, a sufficient number of rays to produce the required intensity of light can be collected from each point of an object, and passed through the pupil of the eye, and if at the same time the axes of the extreme pencils are bent by this lens, or combination of lenses, so as to enter the eye under a sufficiently large angle, while the rays of each pencil are made parallel, or but slightly divergent, then vision will ensue, no matter how minute, how distant, or how imperfectly illuminated the object may be.

When a pencil of rays proceeding from a point of an object passes through a lens, the rays which pass through at different distances from its centre will diverge from or converge to different points, so that the whole pencil will not any longer diverge from, or converge to, a single point; and from this cause the image of one point will overlap the image of another, and an indistinctness of the object will arise. This source of indistinctness is called the spherical *aberration*. A combination of lenses may, however, be formed, so that the aberration of one shall be corrected by the aberration of the others. Such a combination is said to be *aplanatic*.

Since rays of light proceed in every direction from the points of visible objects, the pencils of light intercepted by a lens for the first time are all *centrical*, that is, their axes all pass through the centre of the lens; but the pencils, upon emerging from this first lens are already determinate both in extent and direction, and consequently will fall, some of them at least, *eccentrically* upon a second lens, that is, their axes

will meet this lens at different distances from its centre. The axes of the most eccentrical pencils will then, after emergence, cross the axis of vision nearer to the lens than will those of the more nearly central pencils; and thus, while the centre of the object is seen distinctly, the parts at a distance from the centre will be distorted, or *vice versâ*. This source of error is called the *spherical confusion*. The spherical confusion is diminished by dividing the desired deviations, or bendings of the axes, between two or more lenses; and it is found by opticians to be a good rule to divide the deviations equally amongst the lenses employed.

The most important source of indistinctness, however, is the dispersion of each ray into rays of different colours refracted at different angles (p. 12), which is called the *chromatic dispersion*. The effect of this dispersion upon a centrical pencil is partly analogous to the spherical aberration, causing the images of neighbouring points to be of finite extent and overlap one another; and it, moreover, fringes the image with colour. An eccentrical pencil is separated by this dispersion into pencils of rays of different colours, the axes of which are bent at different angles; and the imperfection arising from this cause is far greater than that from both the spherical aberration and spherical confusion.

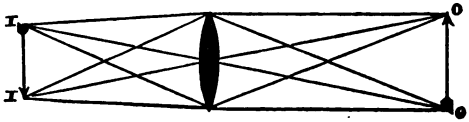
Before stating the manner in which the imperfections arising from the chromatic dispersion are remedied, it will be expedient to explain what is understood by the focal length of a lens. Now a pencil of parallel rays, after passing through a lens, becomes either convergent or divergent, as the lens is convex or concave, and the distance from the surface of the lens to the point to which the pencil converges, or from which it diverges, is called the *focal length* of the lens.

To find practically the Focal Length of a Convex Lens.—Place a lighted candle at one extremity of a scale of inches and parts, with which the lens has been connected in such a manner as to slide along, and always have its axis parallel to the scale. A flat piece of card is also to be made to slide along, so as to be always in a line with the light and the lens, the lens being between the light and the card. The lens and card are then to be moved along, backwards and forwards, till the least distance between the card and light is discovered at which a clear image of the light is formed upon the card; and this distance is four times the focal length.

The imperfection arising from the chromatic dispersion is

remedied, for the centrical pencil, by making a compound lens of two or more lenses of different substances, as flint glass and crown glass, which are fitted close together, and are of such focal lengths that the chromatic dispersion of one is counteracted by the chromatic dispersion of the other. The effect of the chromatic dispersion upon an eccentrical pencil is remedied by setting two or more lenses at proper distances depending upon their focal lengths: such a combination of lenses, as applied to telescopes and compound microscopes, is called an achromatic eye-piece.

When an object, o o, is placed at a distance from a convex lens greater than its focal length, the divergent pencils of

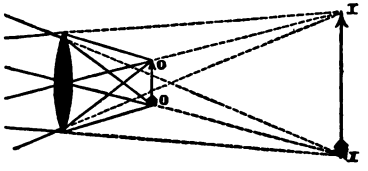


rays, proceeding from every point of the object, become, after passing through the lens, convergent, and at a certain distance from the lens,* having converged nearly to points again, form there an inverted image, I I, of the object. The essential difference between any point in this image, and the corresponding point in the object itself, is, that the latter emits light in all directions, while the light from the former is limited to the pencil which has been transmitted through the lens, and is consequently determinate both in magnitude and direction. If, however, a screen be placed at the required * distance from the lens, a picture of the object in an inverted position will be formed upon this screen, and from each point of this picture light will be emitted in all directions in the same manner as from the points of the object itself. The single pencil of light from any point of the

* If u be the distance from the lens at which the object is placed, f the focal length of the lens, then v, the distance from the lens at which the image is formed, is determined from the equation $\frac{1}{v} = \frac{1}{u} - \frac{1}{f}$; and, hence, when u is greater than f, v is negative, so that the image is on a different side of the lens from the object. When u is less than f, v is positive, and the image is imaginary, and on the same side of the lens as the object. The linear magnitude of the image is to that of the object as v to u.

object, transmitted through the lens, supplies, however, in this case, the light for all the pencils emitted from the corresponding point of the image; and a very strong light must therefore be thrown upon the object to give a moderate brightness to the picture; more especially if the picture be of larger dimensions than the object. A portion of the light is also absorbed by the lens itself.

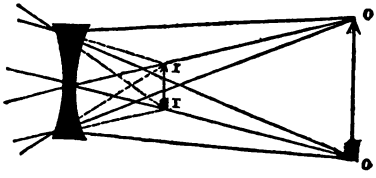
When an object, o o, is placed at a distance from a convex lens less than its focal length, the divergent pencils of rays, proceeding from every point of the object, become, after



passing through the lens, less divergent, as though proceeding from an enlarged image, I I, at a greater distance from the lens than the object, o o. No image could in this case be formed on any screen; but as the rays come to the eye, as though proceeding from an image, I I, this is called an imaginary image.

When then an object is placed before a convex lens, if its distance from the lens be greater than the focal length, the image is on the opposite side of the lens, and is real, and may be either greater or less than the object; but if the distance from the lens is less than its focal length, the image is at a greater distance from the lens on the same side of it, and is erect, imaginary, and greater than the object.

When an object, o o, is placed before a concave lens, the



divergent rays proceeding from every point of the object will, after passing through the lens, become more divergent, as

though proceeding from points between the object and the lens, and will thus form an image, I I, at a diminished distance from the lens, erect, imaginary, and less than the object.

SPECTACLES.

The defects of vision capable of being remedied by spectacles are those called weak sight and short sight.

The sensation of vision is conveyed to the brain by the intervention of an image of the object on the retina, or back portion of the interior of the eye. This image is formed by the rays of light, which enter the pupil, there meeting with, and passing through, a natural double-convex lens, called the crystalline lens. By this lens the pencils of parallel rays from the different points of distant objects, or of divergent rays from objects at a distance of not less than ten inches from the eye, should be made to converge, so as again to be brought back to points on the retina of the eye. By some arrangement, the nature of which has hitherto escaped detection, from the minuteness of the change necessary to produce the effect, the eye is enabled to vary its convergent power within the limits necessary to form distinct images on the retina of objects at various distances from it. When there is no defect in the vision, this distance may be any, greater than ten inches.

The defect called weak sight arises from the convergent power of the eye being insufficient to bring to a focus upon the retina the divergent pencils of rays proceeding from near objects. The focus of the unassisted eye, in this case being behind the retina, must be brought forward by the interposition of convex spectacles. The nearer the object looked at, the greater should be the converging power of the glasses; and hence it comes that very weak-sighted persons require to be provided with more than one pair of spectacles, those adapted to more distant objects being less convex, and those adapted to nearer objects more so.

The defect called short sight arises from the convergent power of the eye being too great. When its defect is not very great, a book or other object can without inconvenience be placed sufficiently near to the eye to throw the focus back upon the retina; but the pencils from the more distant objects presented to the eye, when walking abroad, or in large rooms, converge to a focus before the retina, and to produce distinct

vision of such objects the focus must be thrown back by concave spectacles.

When weak-sighted persons can see distant objects distinctly, but fail to see objects clearly unless they are placed at too great a distance from the eye to be convenient for working or reading, glasses of ten inches focal length will cause the pencils of rays from objects at ten inches distance from the eye to enter the pupil exactly as they would if they proceeded directly from objects at several feet distance, and will therefore bring them to a focus on the retina. When even distant objects are not seen distinctly, glasses still more convergent must be used.

When short-sighted persons can without effort see objects distinctly at a short distance from the eye, concave glasses having a focus equal to this distance will give to parallel rays from distant objects the same degree of divergence as pencils would naturally have proceeding from objects whose distance is equal to the focal length of the glasses; consequently, according to the supposition, the eye will bring such rays to a focus on the retina, and the vision of distant objects will therefore be rendered distinct by such glasses. With eyes so near sighted as to see distinctly objects only when placed at such short distances from them as to be altogether inconvenient, one pair of spectacles will be required for distant objects, and another of less divergent power to see with facility objects at about ten inches distance.

The requisites of good spectacles are twofold: firstly, that the lenses shall be perfectly adapted to perform their office; and secondly, that they shall be so mounted as to enable them to perform their office without fatiguing or injuring the eyes.

With respect to the lenses, in consequence of their slight magnifying power, it is not easy to detect either imperfections in the material of which they are composed, or errors in the form of their curves; nevertheless it is most important that the material should be of equal density throughout, and that the lenses should be ground into a correct optical figure.

I have received from Messrs. Parkes and Son, of Birmingham, some specimens of spectacles, formed from a glass for which they have a patent, and of which they have also forwarded specimens in the unworked state. This material they denominate patent crystal, and the spectacle lenses

ground by them from it appear to me to merit every commendation. I cannot do better than transcribe a portion of their letter accompanying these specimens:—

"You are of course aware that many persons who wear spectacles have a decided preference for Brazilian pebble, on account of its being a better conductor of heat than glass. But you are also as fully aware as myself that it is a *doubly refracting crystal;* and, as it is always cut by opticians, for the sake of economy, in the worst possible direction for optical purposes, viz., in the direction of the axis, instead of at right angles to it, it follows that *optically* this material is much less worth than common glass, on account of the confusion of image produced by it. It is for this reason that we have sought out an improved optical glass, termed 'optical crystal,' which, although not possessed to the same extent of the hard and cool properties of pebble, yet more than compensates for this by its *optical* qualities."

The lenses being good, the next consideration is their mounting, which evidently ought to be such as (1) to render their axes parallel, and (2) to bring their centres exactly opposite the centres of the pupils, when the eyes look straight forward.

To ensure the first of these conditions, great care ought to be taken that, in the original construction of spectacles, the axes of the lenses should be truly parallel, and the mounting ought to be sufficiently strong to prevent any after-derangement of the parallelism of the axes.

To ensure the second condition, it is necessary that the distance between the centres of the lenses should be precisely equal to the distance between the centres of the pupils; for the clearest vision being obtained by looking through the centre of the lenses, and the eyes consequently always endeavouring to look through those centres, their axes, if the distance between the centre of the lenses be too great, will have a tendency to diverge from parallelism, as in the case of an outsquint; while if the distance between the centres of the lenses be too small, the axes of the eyes will have a tendency to converge, as in the case of an insquint.

Persons using spectacles should therefore have the distance between the centres of their eyes exactly measured, and select mountings for their spectacles corresponding with this distance.

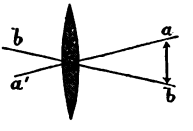
To enable spectacles to be selected, whose focal length

is best suited to distinct vision for reading or working, opticians have an instrument fitted up termed a *visometer*, which contains an object to be looked at, placed at about ten inches distance from its front. In this are two holes, at a distance apart equal to the ordinary distance of the centres of the eyes, and, by turning a handle, while looking through these holes, a variety of lenses are brought in succession before the eyes, which are thus enabled to select the focal length that affords distinct vision with the greatest ease and comfort to them.

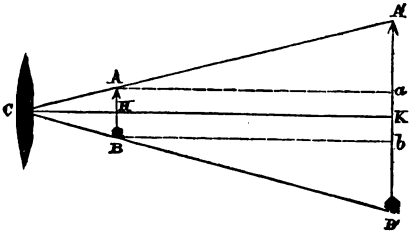
As the most perfect vision with spectacles is produced when the eye looks in the direction of the axis of the lens, and imperfection always attends oblique vision through them, which imperfection is greater the greater the obliquity, persons using spectacles are obliged to turn their heads, when those whose sight does not require their assistance merely turn the eye. To diminish this inconvenience the late Dr. Wollaston suggested the use of menisci or concavo-convex lenses, instead of the double concave or double convex lenses ordinarily used. The effect of these lenses, as compared with the double concave or convex, is that objects seen obliquely through them are less distorted, and that, consequently, there is a greater freedom of vision by turning the eye without turning the head, from which property they were named *periscopic spectacles*.

MAGNIFYING POWER OF LENSES.

The apparent magnitude of an object, seen through a lens, depends upon the angle at which the axes of the pencils from its extreme points enter the pupil of the eye: the further the eye is placed from the lens, the more eccentric are these pencils, the more their axes are inclined, and the greater is the apparent magnitude of the object. When, however, the eye is placed close to the lens, which we shall suppose it to be in estimating the magnifying power, the axes, *a a'*, and, *b b'*, of the pencils from the points *a* and *b*, after passing through the centre *c* of the lens, diverge at an angle, *a' c b'*, equal to the angle, *a c b*, that the points subtend at this centre. Suppose the object A B, when placed before a lens at a distance less than its focal length, to be seen distinctly by



the eye placed immediately behind the lens. The most distinct view of the object will evidently be obtained when the object is placed at such a distance, that the virtual image A′ B′, from which the rays diverge after passing through the lens, is at that distance from the lens at which the eye has the power of distinct vision. This varies in different indivi-



duals, and consequently the magnification produced by the use of the lens depends not only on the focal length of the lens, but also on the range of sight of the individual.

The exact distance, C H, from the centre of the lens at which the object should be placed is readily computed as follows:—Let x represent this distance, f represent the focal length of the lens, and d represent the distance, C K, of distinct vision in the case of the observer: then it is evident that the pencils of rays proceeding from the object, A B, at the distance x, must, after passing through the lens, have the same divergence as though they proceed from a virtual image, A′ B′, at the distance d, or, in other words, their virtual foci must be at this distance. Hence we have the condition expressed by the equation,

$$\frac{1}{d} = \frac{1}{x} - \frac{1}{f}; \text{ and, therefore, } x = \frac{df}{d+f}.$$

Now, without the intervention of the lens, the object, in order to be distinctly seen, would have to occupy the position $a\ b$, under the angle a C b, whereas, by the use of the lens, it is seen under the angle A C B, and being mentally referred to the distance of distinct vision, appears of the same magnitude as though it really occupied the space A′ B′ of its virtual image. The magnification of the object is therefore correctly represented by the ratio of A′ B′ to $a\ b$, which is the same

with that of A B to $a\ b$, or of C K to C H, that is of d to x, and is therefore represented by the value of the fraction $\frac{d}{x}$. Now, we have seen that

$$x = \frac{d\,f}{d+f};\ \text{and, therefore,}\ \frac{d}{x} = \frac{d+f}{f};$$

and this expression represents the magnification of the object for the individual whose range of sight or distance of most distinct vision is d.

It appears, then, that the magnification is greater for long-sighted than for short-sighted persons. Assuming, however, the magnifying power to be that number which represents the magnification for a person of the average range of vision, say ten inches, this magnifying power would then be properly represented by the fraction $\frac{10+f}{f}$.

There is no objection to this mode of estimating magnifying power, and it is only necessary to consider that for long-sighted persons the actual magnification is somewhat greater than this, while for short-sighted persons it is somewhat less.

For lenses of very short focal length, the expression $\frac{10+f}{f}$ becomes nearly equal to $\frac{10}{f}$, and hence the magnifying power of such lenses has sometimes been estimated by this ratio. Unfortunately, this has led to some writers unthinkingly giving the ratio $\frac{10}{f}$ as an approximate estimate of magnifying power for all lenses. The absurdity of such a blunder will be manifest, when we apply such a formula to estimate the magnifying power of a convex lens of ten inches focal length; for it would make it appear to produce no magnification at all, while convex lenses of more than ten inches focal length would by the same rule actually produce a diminution, instead of an enlargement, of the apparent size of an object.

The only unambiguous mode, then, of designating the power of lenses is by stating their focal length, and any person, by observing his own range of natural vision, can compute the magnification which they will produce for himself from the expression $\frac{d+f}{f}$; thus, *add the focal length to the range of sight or distance of most distinct vision, and divide the*

sum by the focal length, and the quotient will represent the magnification, or apparent enlargement, of the object.

The following table exhibits the magnifications produced for persons with three different ranges of sight:—

Focal Length of Lens.	Magnification $\frac{d+f}{f}$		
	Short Sight Range, 5 inches.	Ordinary Sight Range, 10 inches.	Long Sight Range, 20 inches.
½ inch	11	21	41
1 „	6	11	21
5 inches ..	2	3	5
10 „ ..	1½	2	3
20 „ ..	1¼	1½	2

From the examination of these numbers, it will be seen that the long-sighted person derives far more advantage from the use of a lens, especially from a lens of short focal length, than the short-sighted person, the advantage being estimated by a comparison of the apparent magnitude of the object seen with the lens, with that seen by the unassisted eye: thus, a person whose range of most distinct vision is five inches, sees an object through a lens of half-inch focal length magnified to eleven times the size in linear dimensions, at which it appears to his unassisted vision, while to a person who, with the eye alone, sees objects most distinctly at a distance of twenty inches, they would appear through the same lens to be increased forty-one times in linear magnitude.

It must, however, be borne in mind that the terms long sight and short sight are, in fact, synonymous with the terms weak sight and strong sight, so that the short-sighted person may be said to have a microscopic eye. The actual magnitude of the pictures formed upon the retina, which may be considered as a measure of the power of vision, are directly proportional to the angles subtended by the object at the pupil of the eye, and are therefore very nearly in the inverse proportion of the distance of the object from the eye.

The natural vision, then, of a person whose distance of distinct vision is five inches may be considered four times as powerful as that of a person who has to remove objects to a distance of twenty inches in order to view them most clearly. Minute objects, which the former could examine with the

naked eye, could only be examined with equal facility by the latter through a lens of six inches and two-thirds focal length, enabling him also to bring the object within five inches of his eye, and thus producing for him a fourfold magnification of the apparent magnitude. With a lens of a focal length of half an inch, the place of the object to be viewed most distinctly would be $\frac{5}{11}$ inch from the lens for a person whose natural distance of distinct vision is five inches, and $\frac{2}{41}$ for one whose natural distance of distinct vision is twenty inches. Hence it appears that with such a lens the object would have very nearly the same angular magnitude to both individuals; and, consequently, that with lenses of high powers all eyes are enabled to see minute objects with nearly equal facility and distinctness.

CHAPTER IV.

BINOCULAR VISION.

THE STEREOSCOPE.

THE stereoscope is an instrument which, by an exaggeration of the effects of binocular parallax, creates such strong impressions of perspective and relief as raise emotions of delightful surprise and astonishment. Pictures delineated upon a flat surface, being placed in the instrument and viewed by its means, give to the mind ideas of the solidity of objects, not only stronger than can otherwise be represented by the best executed drawings or paintings, but actually stronger, in the case of large objects, than could be produced by direct observation of the objects themselves. In fact, it presents to us not merely views on a reduced scale of the pictures presented to the eye by nature, but gives to these views all the effects of solidity, which would be perceived in models of the objects executed on a sufficiently small scale to be looked at from a very short distance.

To comprehend the effects produced by the stereoscope, it will be necessary to revert to the principles upon which the impressions derived from vision are based. The perception of relative position, form, and magnitude, is originally due to impressions acquired by the sense of touch; and it is only by a comparison with these previously acquired impressions, of

their apparent outlines and varieties of light and shade, that the mind can make use of the eye in forming its judgment; but the continual repetition of this act of comparison, every time that the sense of vision is exercised, causes it to be performed with such facility and rapidity, that the mind, unconscious of any mental effort, imagines magnitude, form, and position to be the immediate subjects of visual perception, instead of their merely being judged of by an experience that, reckoning from the time of unconscious infancy, has been imperceptibly acquired.

This unconscious experience, among its other effects, not only causes us to regard as derivations from a single object the pictures presented by them to each eye, but, moreover, when there is a sensible difference in these two pictures, conveys to us the impression not of the form and position of the object as presented to either eye, but of a modification of the two.

This case does not occur in looking at distant objects, that is, so distant that the distance between the two eyes is as nothing in comparison; and in this case the effects of perspective and relief are produced solely by varieties of light and shade, and of distinctness; and if these varieties be transferred by the painter to his canvas, the impressions of distance and relief conveyed by his picture will approach those received from the immediate view of the objects themselves with a closeness limited only by his skill in transferring them with fidelity and precision.

Parallax is a term applied to the cause which produces an apparent difference in the appearance of objects, arising not from any actual changes in their real positions, but to a change in the position from which they are viewed. It is, in fact, the angle subtended at the place of the object by two positions, from which it is viewed, that is termed parallax. Now it is manifest that, in looking at objects first with the right eye and then with the left, a change in the point of view takes place, and the apparent difference in their aspects from this cause is due to binocular parallax, or the angles subtended by the centres of the two eyes at the places of the objects. In the case of objects whose distance bears such a large proportion to the distance between the eyes that there is no sensible difference between the picture formed by them on the retina of one eye, and that formed on the retina of the other, the phenomena due to binocular parallax are not developed, and perceptions of perspective and relief are due solely to varieties of light and

shade. But in objects whose distances from the observer are not many times the distance between the two eyes, the binocular parallax becomes considerable, and the phenomena developed by it very remarkable. For instance, at the distance of ten inches from the eye, which is about that at which small objects are usually viewed with most satisfaction, the binocular parallax is as much as 13 or 14 degrees.

In looking at such objects, then, and to a considerable degree in looking at objects but a few feet distant from us, the following phenomena occur:—(1) parts of such objects are seen by either eye which are not seen by the other; (2) the parts which are seen at the same time by both eyes have not the same apparent relative positions; so that if the observer were to make an exact drawing of the object as viewed first with the left eye closed, and then with the right eye closed, not only would one show a part of the object on the extreme right which would not be shown in the other, and the latter a portion on the extreme left not included in the former, but the more remote parts of the objects concealed by those more prominent would be different in the two pictures, and in point of fact the two pictures would in no part of them be identical. Now in looking at such objects with both eyes open, it is manifest that two such *different* pictures as above described are simultaneously impressed upon the vision, and the mind regarding them as, what from experience it conceives them to be, the production of single objects, takes them as indications of the forms and positions of these objects. Hence it follows that the perception of relief, form, and relative position is much stronger when assisted by the phenomena of binocular parallax than in the case of more distant objects, where this parallax disappears, and the mind can form its judgment only from the outline and varieties of light and shade.

Now in different persons the distance between the centres of the eyes varies to a small extent, and the distance from the eyes best adapted for distinct vision also varies according as they are longer or shorter sighted, and hence the perception of relief when looking at near solid objects must be stronger in some individuals than in others.

If, however, a skilful artist were to make pictures of some object, sufficiently near to him to produce considerable binocular parallax, as viewed first with one eye closed, and then the other, and if by some optically contrived instrument these

pictures could be so presented, each to the eye with which it was drawn, and shut off from the other, that the optic axes directed to them should converge at the same angle as when directed to a single object, each eye obtaining the same view as if the object itself were presented simultaneously to both, the visual perception will be the same as that derived from the view of a single object, and the judgment will be cheated into the conception that it sees but one picture, although astonished at an appearance of relief and solidity equal to, or even exceeding, that derived from looking with both eyes at the object itself. It is manifest, however, that in looking at the two pictures in the manner just described, every one, whether long-sighted or short-sighted, would receive the same view with either eye, and would therefore receive the same impression of relief; and if the draughtsman were to vary his position slightly, so as to make the distance between the two points of view exceed the distance between the centres of his eyes, the appearance of perspective and relief would be exaggerated beyond any that could be produced by a direct view of the object delineated.

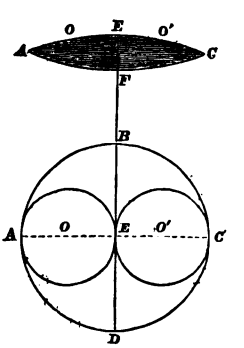
An optical contrivance for enabling an observer to obtain such a view of two pictures as above described is termed a *stereoscope*, the name being derived from the Greek words—*stereon*, "a solid object," and *scopeo*, "I look at," because by its means the two really flat pictures produce the same effect upon the vision as though a solid object were presented to it.

The discovery of the remarkable phenomena that were due to binocular parallax was made by Professor Wheatstone, and in the form of instrument used by him two plane reflectors, placed at right angles to each other, were enclosed in a box having two eye-holes in its front, through which one eye was directed upon one reflector, and the other eye upon the other. The two pictures being placed in the box so that one was seen by reflection from one mirror with the right eye, and the other with the left eye by reflection from the other mirror, the position being so adjusted that the rays from the points of the two pictures, which are the representations of a single point in the original object, should enter the eye as though they had diverged from a common point, the same impression was made upon the vision as though the point of divergence had been a point in a single object from which they had proceeded.

Professor Wheatstone carried his researches further, into the effects which might be produced by presenting to the eyes views

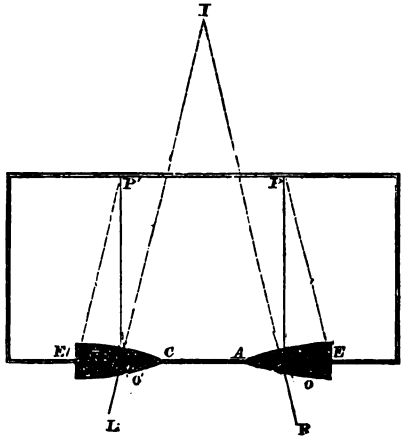
of objects in such aspect as they could not possibly be seen simultaneously, except by artificial means; such as presenting to the left eye that view which would naturally be seen with the right, and *vice versâ;* and a variety of curious and astonishing appearances were the result—objects really hollow being made to appear as standing out in bold relief, and objects in strong relief being made to appear hollow. As a philosophical instrument for the investigation of all the remarkable phenomena due to binocular parallax, the *reflecting form of the stereoscope*, given to it by its inventor, cannot probably be surpassed; but as an artistic instrument for heightening the effects to be produced by the graphic productions of photography, in a manner impossible to be imitated by any skill of the painter, the *lenticular form of the stereoscope*, given to it by Sir David Brewster, has been preferred everywhere by the general public. In this arrangement the visual rays from the two pictures are deflected, and made to proceed to the eye as though diverging from a single object by means of two eccentric double-convex lenses.

These are formed by first cutting a double-convex lens, A B C D, into two semi-lenses, B A D and B C D, and then cutting the two eccentric lenses out of these, their diameters, A E, E C, being semi-diameters of the original lens: thus, if A E C F represent a section of the original lens made by a plane passing through A E C at right angles to its surface, A E F and C E F will represent sections of the two eccentric lenses, which will therefore still have their optical centres at their thickest part, E, while their geometrical centres, o and o′, will lie midway between E and the points A and C.



These two lenses are set in two tubes, which are fitted to a box of a convenient form for receiving the pictures to be viewed by them, the distance between the tubes being made equal to the distance between the eyes. The lenses are so set that their edges, A, and C, are turned towards each other, and their thickest parts, E and E′, are furthest from each other, and that their distance from the back of the box, where the pictures are placed, is equal to their common focal length.

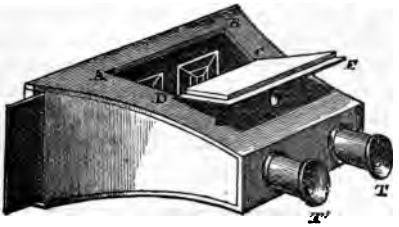
Now, suppose P and P′ to be points on two pictures so placed, representing the same point of an object, as viewed from the right eye, and left eye, respectively; the pencils of rays proceeding from P and P′ will, in passing through the lenses, be so refracted as to form pencils of parallel rays, each refracted ray being parallel to the lines P E or P′ E′, joining P and P′ with the optical centres, E and E′, of the lenses; and, conse-



quently, the points P and P′ will be seen in the directions O I and O′ I, parallel to E P and E′ P′, as the single point I, in which O I and O′ I meet. In like manner every pair of points in the pictures, representing the same point of the object, will be seen as a single point of a solid, viewed by both eyes. The effect produced, then, by the combined pictures is identical with that of a solid object, placed at the same distance from the eyes as I is from the lenses. The pleasing effects produced by this instrument are heightened by the magnifying power of the lenses.

The annexed figure shows the form in which the lenticular stereoscope is usually constructed. The tubes, T, T′, containing the lenses, draw in and out, so as to adapt the foci to different eyes, while they are prevented from turning round by pins and slots, so as to keep the lenses in their proper relative positions. The pictures, if opaque, are illuminated

through the opening A B C D, and the inside of the lid C D E F, may be formed into a mirror, to increase the illumination. Transparent pictures are illuminated through the back of the



instrument which is formed of ground glass, the lid in this case being closed.

Views of geometrical figures, as they would appear from the different positions of the two eyes, may, by rule and compass, be made with great precision, and in presenting such views to the instrument, some of the most interesting and instructive effects of the stereoscope are exhibited; but the impracticability must be apparent of producing two pictures by any process of hand-drawing, which should represent a portrait, or any artistic object, as viewed by each eye in succession, with the precision indispensable for the production of the stereoscopic effect. The contemporaneous discovery of the photographic art has lent its aid to the stereoscope, and produced with facility, not only pictures representing the effects of binocular parallax upon small objects at short distances from the eye, but also pictures imitating the effects of binocular parallax on objects so distant that they would really have no sensible binocular parallax at all.

Thus, let two lines be drawn from the centre of an object at an angle equal to that at which the lines of vision are made to converge by the lenses of the stereoscope. Let two photographic cameras be placed on these lines, at equal distances from the centre of the object, and having their optic axes directed to that centre. The pictures thus produced on a small scale are such as might have been taken from near points of view of a model of the building, constructed on an equally small scale; in which case the distance between the points of view with the same amount of parallax, would not have been greater

than the distance between the eyes. When these pictures are viewed in the stereoscope, the perception of perspective and relief, owing to the exaggeration of binocular parallax, is much stronger than any that could be produced by the view of the building itself; and is, in fact, the same as would be derived from a near view of a reduced model of the building, the distance between any two points in the model bearing the same relation to the distance between their originals in the building, as the distance between the two eyes bears to the distance apart at which the two cameras were placed, to take the pictures.

CHAPTER V.

MICROSCOPES.

THE SIMPLE MICROSCOPE.

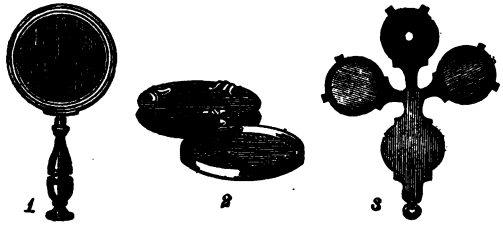
The microscope is an instrument for magnifying minute but accessible objects. A convex lens is a microscope, but the imperfections of such an instrument have been already explained (p. 20), and the greater the power of the lens the greater will be these imperfections. For small magnifying powers, then, convex lenses may be used, as they are for spectacles; but for obtaining good images with high magnifying powers a combination of lenses must be used.

Single lenses, then, of five or six inches focal length, constitute the microscope in its feeblest form, and are very useful for many purposes; such as the reading of very small print, the examination of photographs, the inspection of plants by the naturalist, and of anatomical subjects by the medical profession.

Simple microscopes of the above form are called magnifiers, or magnifying glasses. Fig. 1 represents a mode of mounting a glass of this kind for the library table, and Fig. 2 a convenient form of mounting for a magnifier to be carried in the pocket. In Fig. 3 two such magnifiers are mounted in one frame with a diaphragm. The lenses are of different powers, and can be used separately or in combination. In the latter case, the diaphragm is placed between them, and diminishes the effects of spherical aberration.

Glasses of short focal lengths are used by miniature

painters and engravers. They are usually mounted in frames of tortoiseshell or horn. Watchmakers, jewellers, gem sculptors, &c., make use of glasses of about one inch focal



length. They are usually mounted in a horn cell, in the shape of a truncated cone. The larger end of the cell is made of such a size as to be conveniently held by the contraction of the muscles surrounding the eye, and the lens being fixed at the smaller end of the cell, the object to be examined or manipulated is brought to a distance of about an inch from the lens, and seen by pencils of parallel, or nearly parallel, rays, emerging from the lens and entering the eye. Sometimes, to avoid the inconvenience of holding the magnifier either in the hand or in the manner just described, a stand is made use of, consisting of a jointed arm attached to a ring, which slides upon a vertical rod, and can be fixed at any desired height by a tightening screw: the arm carries a socket at its extremity, into which the cell that holds the lens can be dropped, and the object, placed on the table beneath it, can be viewed without inconvenience or fatigue.

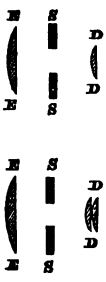
Small glass spheres are used as microscopes of high powers; but a thin lens composed of any more highly refractive substance is preferable; because, the focal length of the sphere measured from its centre being but three semi-radii, the distance of the object from the surface is only one semi-radius, which prevents its being used in the examination of delicate objects. The refracting sphere is much improved as a microscope by cutting a groove round it in a diametrical plane, and filling it up with some black opaque substance. By this contrivance the aperture is diminished, with

tracting the field of view, and all the pencils are necessarily centrical. A lens formed in this manner from a sphere of glass is called a Coddington lens, from its supposed invention by the eminent mathematician of that name. It appears, however, to have been one of the contributions of Sir David Brewster to optical science.

The annexed figure represents an elegant and convenient form of mounting the Coddington lens, as a pocket microscope.

Microscopes have been made of diamond and sapphire, and the aberration is much less than with glass. Sir David Brewster employed, as a microscope, a drop of Canada balsam or turpentine varnish upon a thin plate of glass, of which the surfaces were exactly parallel. This is a very ready way of forming a plano-convex lens, and if kept free from dust will last some time.

Such glasses as have been just described may be conveniently used, for the inspection of transparent objects, when high powers are not required; but when higher powers are necessary, or the objects are opaque, combinations of two or three plano-convex lenses, with their convex sides towards the eye, may be used. These are called doublets or triplets. The triplet is the most powerful of these combinations, and in it the two lenses nearest to the object are in contact, and play the part of the single lens, which is sufficient for lower powers, the construction being in all other respects the same as for a doublet. Between this lens, D D, and the posterior lens, E E, a diaphragm, S S, is interposed, consisting of a circular disc of metal, with a hole in its centre, to cut off scattered rays not necessary for the formation of the imaginary image.



The lenses are usually set in two thimbles, one of which

screws into the other, in order that their mutual distance may be adjusted so as to produce the best effect. When unscrewed, the lenses can be used singly for very low magnifying powers; and, again, the same posterior glass, E E, can be used either with a single anterior lens, D D, to form a doublet, or a double lens to form a triplet, according to the magnifying power desired.

The advantages of the doublet form are, firstly, that the injurious effect of spherical aberration is much diminished; and, secondly, that the object can be placed at a much greater distance from the anterior lens D D, and can thus be more conveniently manipulated; while it can also be illuminated by a light thrown on it from that side which is presented to the glass.

Such lenses, or combinations of lenses, as those above described, in which the object is viewed directly, are called *simple* microscopes. In their most useful form they are mounted in a framework, either to be held in the hand, or placed on a table, having a contrivance for holding the object, so that it may be kept steadily in the axis of the lens or lenses, and moved to or from them with a smooth and easy motion.

Hand-frames are made to fold into a small compass and fit into a case to be carried in the pocket; but, when portability is not a chief desideratum, a more stable mode of mounting should be adopted. The following is the arrangement of *Darwin's Dissecting Single Microscope.*

The base A of the instrument is formed of a solid block of oak or mahogany. Into this is firmly screwed the pillar B, into which the triangular bar C C slides, and is raised or lowered by a rack and pinion with a slow and easy motion, by turning either of the milled heads L, L. On the top of the bar revolves a square head, through which passes a horizontal arm, D E, which is advanced or retired by turning either of the milled heads H, H, and carries at one extremity a socket, E, for holding a lens that forms the microscope. At the end D of the arm is a slot, to receive the stem of a ring that holds the large doublet S, this stem being fixed by the screw G. The stage I, is a ring, three inches in diameter, revolving with friction upon a fixed piece firmly attached to the top of the pillar B. Into this ring fit the following pieces:—1. Either of the large saucers, T and U, with glass bottoms for holding objects in water; a piece of cork, loaded under-

neath with lead, to sink it to the bottom, being placed in the saucer, when illumination from beneath is not required. 2. A piece, o, of boxwood, covered with cork, on which objects may be pinned. 3. A brass plate, R, with central aperture one inch and a half in diameter. Into the aperture of the plate R fit smaller saucers and various pieces for holding objects, and also a holder, P, for glass slips. K is

a concave mirror, having a cap with small flat mirror, for the illumination of transparent objects: it can be set at any desired angle, and the collar to which it is attached slides stiffly on the pillar B, so as to be set at any desired distance below the stage. The light from the mirror can be also regulated by the diaphragm M, fitting below the stage; or it can be entirely excluded by turning the stop, N, over the aperture of

the diaphragm, when opaque objects are under observation, such objects being illuminated from above by an independent condensing lens.

The object is brought into focus by raising or lowering the arm D E, by means of the rack and pinion movement of the bar C C; and by revolving the arm D E, and moving it backwards and forwards, by turning one of the mill heads H, the lens or doublet can be carried over every part of the field of view.

Queckett's Single Dissecting Microscope is very simple and effective in its construction, and very moderate in price.

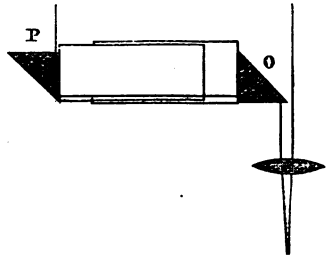
Beck's Improved Dissecting Single Microscope.—The base A, of this instrument is of solid mahogany, and from it rise four pillars, B, supporting, at the height of four inches, a stage six and a half inches square, rounded at the corners. This stage carries a circular plate of six and a half inches diameter, which is revolved by turning the milled head E, beneath the stage. Above this is a smaller circular plate, with sliding motion, having a central aperture of one inch and a half diameter, for receiving various pieces to hold the objects to be examined. The horizontal arm H, with socket at its extremity for carrying the lenses,

has a limited revolving motion on the top of the bar I, so that it can be turned away from the stage to the left hand, but, when turned to the right, is stopped with the centre of the socket over the centre of the stage; the bar I, which rises from the more remote left-hand pillar, is raised or lowered with a slow and easy motion by turning the milled head K; and as the amount of this motion extends to the whole length of the pillar B, objects of considerable thickness can be placed between the lens and the stage. The mirror L, for the illumination of transparent objects, rises from a recess in the base A, and above the stage is a condensing lens, M, for the illumination of opaque objects.

In this microscope the lens remains stationary over the object, and the latter is moved by the revolving and sliding plates, so as to bring every portion of it into the most favourable position for examination, while the axes of the lens and mirror maintain their coincidence: the sliding plate has a motion of three quarters of an inch in every direction, so as to bring every part of a circular field of an inch and a half diameter under the axis of the magnifier. The magnifiers most in use are Coddington lenses, from one inch to one-eighth of an inch focus.

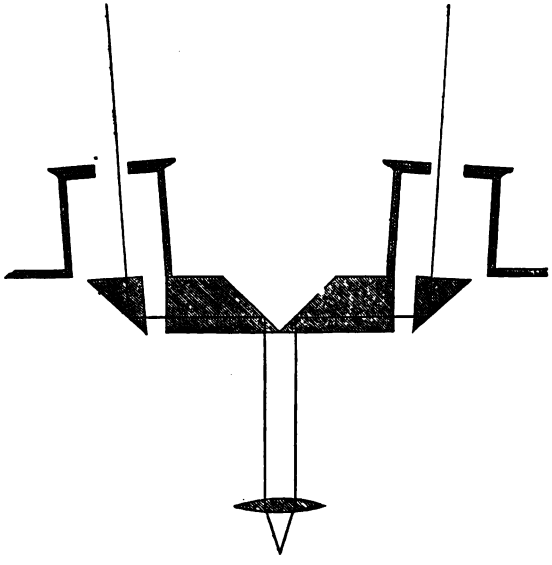
Single Microscope, with Binocular Vision.—Not only does the

employment of a single eye in lengthened microscopic examination fatigue and distress it, but the continued use of a monocular instrument will produce an unequal range of vision in the two eyes; moreover, the stereoscopic effects due to binocular parallax (p. 32) are entirely lost. With such low powers as are employed for ordinary spectacles, each eye is supplied with a separate lens, and all the comfort and perfection of binocular vision are retained; but when magnifiers of less than two inches in focal length are made use of, the employment of two lenses is impracticable, and it becomes an important problem to find a mode of realising the effects of binocular and stereoscopic vision, when an object is to be viewed by means of pencils proceeding from a single lens. Now the distance from centre to centre of the two eyes being about two inches, and the ordinary range of most distinct vision about ten inches, it is manifest that if the latter distance were reduced to one inch, there would be the same amount of binocular parallax with two imaginary eyes having a distance from centre to centre of one-fifth of an inch; if the distance of the object were reduced to half an inch, the distance between the imaginary eyes need only be one-tenth of an inch, and still the amount of binocular parallax would be the same as with the natural vision, and consequently the same stereoscopic effects would be produced. Hence, with a lens of short focal length, the two halves of the lens itself may be made to perform the office of the two imaginary eyes, and by any contrivance for directing the rays from the right half of the lens to the right eye, and those from the left half of the lens to the left eye, not only the ease and comfort of binocular vision, but also the stereoscopic effects of binocular parallax may be restored.



Beck's Binocular Prisms.—Our figure (p. 44) of Beck's improved single dissecting microscope is represented with these prisms applied. Since rays diverging from an object very nearly in the focus of a lens become almost parallel after their passage through the lens, the eye can be placed nearer to the lens, or removed further from it, to a con-

siderable extent, without imparting indistinctness to the view of the object, and thus it can be viewed by both eyes at the same time, though one may be, in effect, farther removed from it than the other. The prisms O and P are placed at the ends of two semi-circular tubes, one of which, carrying the prism O, is fixed to the arm R, and the other, carrying the prism P, slides in the first, so that the prisms can be set at different distances, to suit the varying distances between the eyes of different persons. The arm R, being placed on a pivot above the arm H, carrying the lens, is turned to the right, and meets with a stop when the prism O covers the left-hand half of the lens. The tube carrying the prism P being, then, pulled out, until the distance between the prisms is equal to the distance between the eyes of the observer, the object is



viewed directly by the right eye through the right half of the lens, while the rays passing through the left half are reflected by the prism O along the tube to the prism P, and thence to the left eye, which thus obtains the view of the object presented to the left half of the lens. By this arrangement

the field of view presented to the left eye is smaller than that presented to the right, and the centre part only, that is common to both eyes, is stereoscopic; nevertheless the addition of these prisms to the microscope presents a very great improvement in the delineation of the objects.

Nachet's Prisms.—The form of these prisms and their arrangement, as adapted to the single microscope, is represented in the accompanying figure. The rays from either half of the lens are reflected through paths of equal length, those from the right half to the right eye, and those from the left half to the left eye; and the prisms G, G, are so inclined as to make the pencils of light to either eye, from the same point of the object, diverge, as though proceeding from a single point at the distance of most distinct vision, as they do in the stereoscope (p. 35). The object is, by this arrangement, presented to both eyes with exactly the same degree of magnification; and, the extents of the fields of view being also equal, the delineation is admirable, and the stereoscopic effect complete.

Beck's Improved Dissecting Single Microscope, with Nachet's prism, may be considered, therefore, an instrument of high perfection.

THE COMPOUND MICROSCOP .

Microscopes in which an enlarged optical image of the object is first formed, and this image then viewed by a combination of lenses, as an object would be by a simple microscope, are called *compound* microscopes.

To avoid the indistinctness arising from chromatic aberration, microscopes used to be constructed in which the enlarged optical image was produced by a concave reflector; but the very great improvements which have, in the present generation, been made in the construction of object-glasses, has rendered them so superior to reflectors for the formation of the enlarged image, that the reflecting microscope has fallen entirely into disuse, and we shall, therefore, confine our attention entirely to the refracting microscope.

The necessary conditions of distinct vision with the compound microscope, like those for vision with the naked eye, are —1. That the pencils of light which enter the eye from every point of the object under examination, should have the same degree of divergence as if proceeding from the distance at

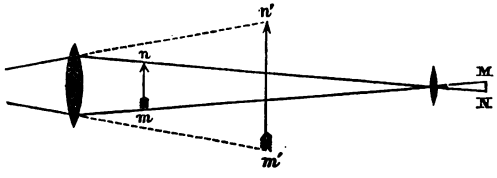
which the most distinct vision is obtained with the naked eye; 2. That the axis of the pencils proceeding from the extreme parts of the object, enter the eye under a sufficient angle, or, in other words, that the apparent or virtual image subtend an angle of sufficient magnitude; 3. That there may be a sufficient quantity or intensity of light entering the eye from each point of the apparent or virtual image, or, in other words, that every point of this image be sufficiently illuminated—a condition which necessitates an illumination of the object in proportion to the magnitude of the angle under which its image is presented to the eye. The two first conditions must be satisfied by the apparatus for the magnification of the object, and the third by that for its illumination.

The magnifying apparatus of the compound microscope is constructed upon the two following principles:—

1. The formation of an enlarged optical image of the object to be examined.

2. The magnification of this enlarged image, as if it were the object itself viewed by a simple microscope.

In the rudest and most imperfect state of the instrument, as constructed by its first inventors in the beginning of the seventeenth century, these principles were carried out by the means of two lenses, called respectively the object-glass and eye-glass, fixed at the opposite ends of a tube, or rather of two



tubes made to slide one within the other, so that the distance apart of the two lenses might be varied within certain limits. The object-glass O, was a lens of short focal length, and the object M N, being placed at a very little distance beyond its focus, an inverted and enlarged image, *m n*, of the object was formed at a much greater distance from the object-glass, than that of the object, M N.

The image *m n* was then viewed through the eye-glass E, which performed the office of a magnifying-glass, and was

adjusted at such a distance from the image *m n*, that the pencils of rays, after emergence, had the same divergence as though they proceeded directly from an object, *m′ n′*, at the distance from the eye best adapted to distinct vision. The same impression was then produced as though the object were really of the magnitude *m′ n′*, and viewed by the naked eye.

The ultimate magnification produced by the instrument was evidently the product of the magnifications produced by each of the lenses. The magnification produced by the object-glass depended upon the focal length of this lens, and the distance from it at which the object was placed: this distance, however, must exceed the focal length. The magnification produced by the eye-glass depended upon its focal length, and upon the distance of most distinct vision for the naked eye of the observer, and was almost proportional to this distance; so that for an observer seeing most distinctly with the naked eye at twenty inches distance, it was nearly four times as great as for one seeing most distinctly at five inches distance. To the two observers the magnified image would, in fact, have very nearly the same angular magnitude, whereas, the object, viewed with the naked eye, to the long-sighted observer would appear under an angular magnitude one-fourth only of that under which it would appear to him with the stronger vision.

From the mere consideration of the fundamental principles of the instrument, the dimensions to be given to it, as well as the effects produced by it, may be easily computed. Suppose, for example, that the focal length of the object-glass be one-fifth of an inch, and that of the eye-piece three-fourths of an inch: if then the object be placed at $\frac{1}{20}$ of an inch beyond the principal focus, or $\frac{5}{20}$ of an inch from the centre of the lens, a real inverted image will be formed at the distance of ten and one-fifth inches from the lens, on the other side of it, and the magnification of the object-glass will be fifty, so that for an object $\frac{1}{20}$ of an inch in diameter, the diameter of the image would be one-fifth of an inch. Then, for an observer whose distance of most distinct vision is ten inches, the eye-piece must be placed at a distance of $\frac{3}{43}$ of an inch behind the image, and the magnification produced by the eye-piece will be $14\frac{1}{3}$; so that the entire magnification will be $50 \times 14\frac{1}{3} = 716\frac{2}{3}$. On these hypotheses the distance between the eye-glass and object-glass, or the length of the

instrument, would be $10\frac{1}{3} + \frac{2}{3}\frac{2}{3} = 10\frac{1}{2}\frac{2}{1}\frac{2}{3}$ inches, or very nearly 11 inches.

The angular magnitude of the image, as viewed by the above observer, would be 16°, while the angular magnitude of the object itself, viewed by him with the naked eye, would be only 1′ 22½″.

A short-sighted person, whose length of sight was five inches only, would see the image with an angular magnitude of 17° 3′; and a weak-sighted person, whose length of sight was twenty inches, would see it with an angular magnitude of 15° 27′; while the angular magnitude of the object itself viewed by them with the naked eye, would be 2′ 45″ for the strong sight, and only 41¼″ for the weak sight.

With the same object-glass and eye-glass other degrees of magnification could be obtained by placing the object at a greater or less distance from the object-glass; but it would be necessary at the same time, to shorten or lengthen the distance between the two glasses, since the place of the image would approach towards the object-glass or recede from it, as the object was moved farther off or brought nearer. It appears, then, that by placing the eye-glass and object-glass in separate tubes, sliding one within the other, great variations can be made in the magnifying power, without making any change in the lenses. It will appear hereafter that a contrivance of this kind not only enables us to arrange the magnification to an exact extent, to meet special purposes, but also allows the introduction of additional apparatus for reinverting the image, and supplies the means of setting a binocular instrument to suit varying distance between the eyes of different observers.

The description of the instrument in its original crude form given above, has served to illustrate its fundamental principles; but the imperfections arising from the spherical and chromatic aberrations and distortions, being magnified with the magnification of the object, rendered it almost useless. The researches of modern microscopists, however, have led to the substitution for each of the simple lenses, originally forming the object-glass and eye-glass, of compound pieces, in which the imperfections produced by the several lenses, are so balanced as to counteract one another to a most marvellous extent; and a degree of perfection in the construction of microscopes has thus been arrived at which leaves little to be desired.

The Object-piece, or Objective.—Microscopes, then, are now constructed with compound object-glasses, or, more properly, object-pieces, in which the chromatic aberration is over-corrected, so as to produce what may be called negative chromatic aberration. Were the object-piece itself made perfectly achromatic, it is manifest that the chromatic aberrations thus effaced would be more or less reproduced by the eye-piece, unless this also were made perfectly achromatic; but the desired result is obtained more simply by constructing over-corrected object-pieces, to produce such amounts of aberrations and distortions, as will be effaced by aberrations and distortions of an opposite character in the eye-piece; and this expedient has been so far successfully carried out, as to give a result, practically speaking, free from all optical imperfection.

An object-glass consisting of a single lens, having a very high magnifying power, would have so short a focal length, and such great curvature, as to produce great spherical aberration, besides other inconveniences. Several compound achromatic lenses, or rather compound lenses in which the achromatic aberration is over-corrected, are therefore combined to form an object-piece, and by this means the spherical aberration is to a great extent eliminated, and a much larger aperture obtained. The compound lenses of which object-pieces consist, are generally composed of plano-concave and double-convex lenses, forming together plano-convex lenses; and the plane sides are presented towards the object. Were the convex side turned towards the object, the rays diverging from this object would fall upon the convex surface with greater and greater obliquity, as they approached its borders, and would, in fact, be in great part reflected without passing through the lens at all, so that a very small aperture only would be available. This defect is remedied to a great extent by presenting the plane side of the plano-convex lens to the object; but such improvements have been made in object-pieces as to allow of greatly increased apertures, and for this purpose the meniscus form has been given to the object-glasses, their concave sides being presented to the object. In the most powerful microscopes, three compound lenses, mounted so that their axes shall be precisely in the same straight line, constitute the object-piece, or, as it is usually but inappropriately called, the object-glass; and with the great *magnifying* powers now attained, the slightest imper-

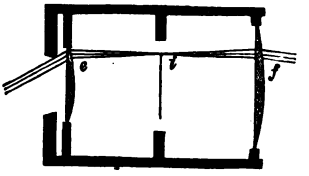
fection would be so magnified as to be highly injurious. It is therefore manifest that the greatest precision in the balance of the aberrations must be arrived at.

Now it is necessary for the preservation of microscopic objects to cover them with thin films of glass, and the aberration produced by these films, if only the 100th of an inch in thickness, will, under a power of 1,500 or 2,000, impair the distinctness of the image. In microscopes, therefore, of the highest powers, the triple lenses which compose the object-piece, are so mounted that their mutual distances can be varied slightly by a delicate screw-action, and by this means a sufficient effect can be produced on the aberrations to neutralize the small amount of positive aberration produced by the glass film which covers the object.

The Eye-piece.—For eye-pieces of low power single lenses may be used. As higher powers are used, with the increased magnification of the image the imperfections would be magnified also, and compound eye-pieces are used, in which a second lens, called the field-glass, is placed in front of the eye-glass. The field-glass intercepts the rays from the object-piece, before they arrive at the position for the formation of an image, and by giving them increased convergence, causes them to produce a smaller image, the whole of which is seen with the eye-glass, while without the intervention of the field-glass the central portion only of the image would be so seen. It is called the field-glass from this property of enlarging the field of view. But not only does it do this, but by concentrating on the reduced image the light, which would otherwise be diffused over the larger, the brightness is greatly increased. The image formed by the object-piece is not flat, but forms a portion of a spherical surface, concave towards the object-piece, and, consequently, convex to the eye; the effect of a single lens as an eye-piece would be to increase this convexity, and it is therefore desirable that the field-glass should have the further effect of altering the form of the image into one convex to the object-piece, just to such an extent as to be corrected by the like tendency in the eye-glass to produce an alteration of curvature, and thus to render the imaginary image seen through the eye-glass flat, or, as it is termed, to produce a flat field.

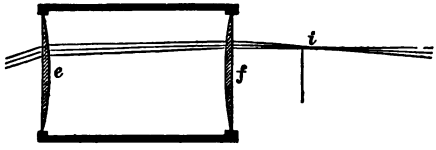
The Huyghenian Eye-piece.—The preceding requisites of a good eye-piece are all fulfilled by the negative eye-piece, *invented by Huyghens* for the telescope, in order to produce

a flat field, but without recognising its power to correct the chromatic aberration. It consists of two convexo-plane lenses, with their plane sides consequently turned towards the eye, their focal lengths and the interval between them being as 3, 1, and 2. The lens, *f*, of greatest focal length forms the field-glass; and when the microscope is arranged for distinct vision of an object, this lens stands between the object-piece and the focus at which it would produce an image of the object, at a distance from the latter equal to half its own focal length. Thus, the pencils of rays from the object-piece, tending to form an image at a distance from the field-lens equal to three-fourths of the interval between the two lenses of the eye-piece, are intercepted by the field-glass, and brought sooner to a focus, so as to form the image, *i*, half way between the two lenses, and consequently in the focus of the eye-glass. A diaphragm is placed in the tube between the lenses, at the point where the image is formed, to shut off all extraneous light, and another diaphragm is placed in front of the eye-glass. In this eye-piece the refractions of the axes of the pencils are equally divided between the two lenses, by which means the spherical confusion is much diminished; the forms of the lenses are also such as to produce but a small amount of spherical aberration, and the relation between the focal lengths of the lenses and the interval between them is such, as to produce a combination, whose aberrations shall so balance those of the over-corrected object-piece, as entirely to eliminate the spherical aberration, and reduce the chromatic aberration to a minimum, leaving only a very pale green tint from the combination of the blue and yellow rays, which is in no way objectionable. This eye-piece, called a *negative eye-piece*, is always to be preferred when we are only seeking to obtain the best defined and most distinct view of an object; but for some purposes it has been necessary that an image should be formed by the object-piece in front of the eye-piece.



Ramsden's Eye-piece.—We have then recourse to the eye-piece, originally constructed for astronomical telescopes by Ramsden, called a *Positive Eye-piece*. This consists of two lenses of equal focal lengths, one plano-convex and the other convexo-plane, so that the convex sides are turned

towards one another, the interval between them being equal to two-thirds of the focal length of either. When the microscope is arranged for distinct vision of an object, the field-lens *f*, is placed at a distance behind the image formed by the object-piece, very nearly equal to one-fourth of its own focal length. The focus of the entire eye-piece is, in fact, situate in front of the field-lens, at a distance equal to one-fourth the focal length of this lens and is therefore a very little



distance beyond the image, and the rays proceeding from the image at *i* emerge from the eye-lens, *e*, parallel, or in the condition best adapted for distinct vision. This eye-piece is not achromatic, but it has very little spherical aberration. Its principal defect is that it does not produce a flat field; so that while the delineation in the centre of the field is good, it becomes indistinct towards the edges.

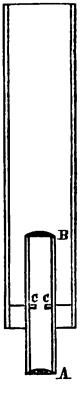
Kellner's Eye-piece.—This eye-piece will give a field of fourteen inches diameter, and is consequently well adapted for a general view of an object; but the delineation is not sufficiently distinct for the examination of minute details. The field-glass is a double convex lens placed in the focus of the eye-glass, and the latter is an achromatic combination of a plano-convex flint lens with a double convex crown lens. The aberrations, however, are under-corrected, so as to balance the aberrations of the object-piece. The field-glass in this eye-piece must be frequently removed, and wiped with a soft leather or piece of silk, as the least speck of dirt upon it, being in the focus of the eye-glass, is seen with magnified dimensions.

Use of Varying Powers.—In the prosecution of microscopic researches, a great variety of magnifying powers are required. Not only are high powers required for very minute objects, and lower powers for larger objects, but, for the complete examination of the same object, a low power is first required, to view its form and character as a whole, *and then, powers* successively higher and higher must be

used, to disclose more accurately its several parts, and the more and more minute features which characterize it. The best microscopes are therefore supplied with several object-pieces and eye-pieces, each eye-piece being adapted for use with every one of the object-pieces; and by this means a number of powers, varying from ten or twelve upwards, is obtained. For powers below thirty or forty, however, simple microscopes may be used.

With the largest and best instruments the makers supply four or five eye-pieces and eight or nine object-pieces, thus producing from thirty-two to forty-five varieties of power; and intermediate powers are produced to a large extent, by changing the distance between the object-piece and the eye-piece. For this purpose the object-piece is fitted into one tube and the eye-piece into another, moving within the former with a fine motion, produced by a rack and pinion. The most masterly skill is required to construct these tubes, so that their axes shall be always in exactly the same right line, and to set the several lenses in these tubes, so that their axes shall also range in the same straight line with the utmost precision. The least deviation in this respect would be fatal to the efficiency of the instrument.

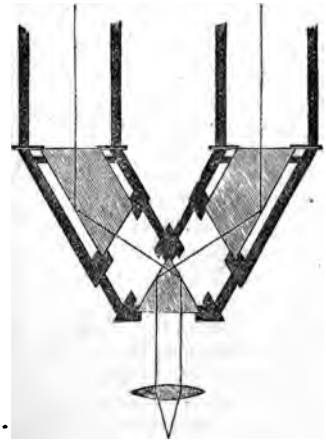
Mechanical Portion, or Body of the Microscope.—We thus come to the consideration of the mechanical portion of the instrument. This consists then of a tube called the *body*, into one end of which the object-piece is screwed, and into the other the eye-piece slides. If it be desired to produce varying powers by changing the distance between the object-piece and eye-piece, the eye-piece is fitted into a tube called a draw-tube. This tube can be pulled out to the extent of six inches, and is graduated at every tenth of an inch, so as to be pulled out with exactness to any desired length. By drawing out the tube the balance of the spherical aberration is slightly disturbed; but this balance is again restored by an arrangement for varying the distance between the lenses which form the object-piece, in a mode to be explained hereafter.



Erector.—Microscopes supplied with a draw-tube can have adapted to them the erector, or erecting eye-piece. It consists of a brass tube, three inches long and five-eighths of an inch in diameter, into the opposite ends of which are screwed two plano-convex lenses, A and

B, and between them is placed a diaphragm or stop, C. It is screwed into the lower end of the draw-tube, with the convex surfaces of the lenses turned towards the eye-piece, which is fitted into the upper end of the draw-tube. This appendage to the microscope fulfils the same office as the two additional lenses introduced into the terrestrial eye-piece of the telescope (p. 88); that is, it reinverts the inverted image of the object formed by the object-piece, and thus gives an erect view of the object with all its parts represented in their relative positions, so that the hand can follow the eye in dissecting.

Binocular Body.—The stereoscopic effects of binocular vision are to be obtained with the compound microscope, as in the simple microscope, by dividing the pencils of light, and removing the rays from one half of the object-piece to one eye, and from the other half to the other. In the first attempts, however, to effect this, the results produced were not stereoscopic, but pseudoscopic; for since the object-glass forms an *inverted* image of the object, it is necessary, in order to produce *stereoscopic* effects, to invert also the two imaginary eyes formed by the two halves of the object-piece, and remit to the *right* eye the rays from the *left* half of the object-piece, and to the *left* eye those from the *right* half.



Nachet's Binocular Body.—This instrument consists of two parallel tubes, the distance between them being regulated by screws; these tubes carry at one end the eye-pieces, and at the other end prisms, which reflect up the tubes the rays reflected to them from the central prism A B C. This prism receives on the face A B the rays proceeding from the left half of the object-piece, and reflects them to the right, and on the face A C the rays from the right half of the object-piece, and reflects them to the left. The distance between the tubes being so adjusted, then, as to correspond

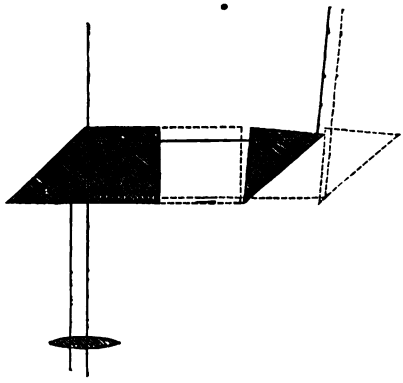
with the distance between the eyes of an observer, upon looking into both tubes, his right eye sees the picture presented to the left half of the object-piece, with the relative positions of all its parts inverted; and, in like manner, the left eye sees the picture presented to the right half of the object-piece. The position of the eyes, as it were, being thus inverted, at the same time with the inversion of the picture, true stereoscopic effects are produced.

The defects incident to this arrangement are the loss of light from the reflections at the four surfaces, through which the whole of the light has to pass, and the fatigue to the eyes from their axes being directed in parallel directions instead of converging to a point, as is natural to them when looking at a near object.

Wenham's Binocular Body.—The arrangement invented by Mr. Wenham is now universally adopted by the microscope makers of this country. It possesses the singular properties that it can be used either as a binocular or monocular instrument, and that it can be adapted to any instrument already constructed as a monocular microscope. It consists of a small prism mounted in a brass box, which slides into an opening immediately above the object-piece, and reflects one half of the rays that pass through this object-piece into an additional tube, attached at an inclination to the ordinary body. The other half of the rays take their usual course entirely unobstructed, and the diverted rays, reflected twice within a single prism, pass through only two reflecting surfaces, and thus suffer only half the loss of light, to which both halves of the rays are subjected in Nachet's Binocular Body, described above. The eye-pieces are placed in draw-tubes, and by racking them out or in, the distances between the axes of the eye-pieces are increased or diminished, to correspond with the distance between the eyes of the observer. This adjustment is very important, and is to be tested by closing each eye alternately, without moving the head; if each eye has then a full and clear view of the object, the adjustment is correct, otherwise the draw-tubes must be racked out or in, until this result is obtained. If the prism is drawn back until stopped by a small milled head, the whole of the rays from the object-

piece pass into the main body, neither the prism nor the additional body interfering in any way with the use of this body only as a monocular microscope. This is a point of considerable importance, as with the highest powers now attained, the division of the light between the two bodies cannot be afforded.

Nachet's Improved Binocular Body.—M. Nachet has adopted Mr. Wenham's plan of diverting only one half of the rays into an additional inclined body, thereby removing the defects noticed above in his original plan; and has also, by a very ingenious arrangement, obtained the means of instantaneously changing

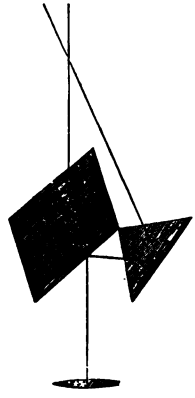


the pictures presented to the two eyes, so as to produce in one case a stereoscopic, and in the other a pseudoscopic, view of the object. Half the rays transmitted through the object-piece are reflected, first from the surface of the prism A to the surface of the prism, B, and then, from this surface into the additional body. When the prisms are in the position represented by the figure, the effects produced are stereoscopic; but when they are in the position represented by the dotted lines, the effects produced are pseudoscopic.

Though so great an improvement when using object-pieces of low powers, the *stereoscopic* binocular should not be employed with the highest powers for the following reasons:—1. The large apertures (p. 51) of these object-pieces produce too great an exaggeration of the stereoscopic effects; 2. Their want of penetrating power (p. 51) renders stereoscopic effects

of little value; 3. The division of the rays of light into two halves is equivalent to a diminution of aperture to an equal amount, and consequently impairs greatly the resolving power in which consists the value of these object-pieces. The use of a single eye, however, for a lengthened observation is very fatiguing; and, moreover, the constant use of a monocular microscope will in time impair the sight by making the range of distinct vision of the two eyes unequal.

To remedy these inconveniences Messrs Powell and Ireland have constructed a prism which, being introduced into the binocular body in place of the Wenham prism, may be used with the very highest power to produce a non-stereoscopic binocular view of the object. The whole of the rays proceeding from the object-piece fall first upon the surface of a glass plate with parallel surfaces; the greater portion of these rays pass through the plate, and pursue their usual course to form an image with hardly any deterioration, while that portion of the light which is reflected from the anterior face of the plate passes into a prism at its side, and is reflected into a second body, where it forms an image for the second eye somewhat darker than the principal image. The mind, however, takes cognizance of the brighter picture in the principal body, while the comforts of binocular vision are fully realised.



Having now discussed both the optical portions of the compound microscope, and the mechanical arrangements of the body in which they are placed, there remain to be considered the accessories for illuminating, and holding the object, and the construction of the stand for supporting both them and the body of the microscope.

Illumination.—The illumination of the object is intended to produce such an effect that the enlarged virtual or apparent image shall be viewed as though it were a real object, seen under the most favourable quantity, quality, and direction of light.

Quantity or Degree of Illumination.—The quantity of light which, proceeding from the object, passes through the in-

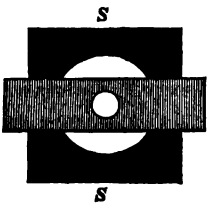
strument, and ultimately enters the eye of the observer, must be sufficient to make every point of the apparent image over which it is diffused, as bright as would be desirable for a natural object observed with the naked eye, and must therefore be intensified in exact proportion to the magnification of the object; and a much greater amount even than this must enter the object-piece, to allow for the quantity lost by reflection at each of the refracting surfaces of the several lenses, and cut off by the diaphragms to correct aberrations and distortions.

Angular Aperture.—The quantity of light which, after proceeding from the object, enters the instrument, and is transmitted through it, depends, *cæteris paribus*, upon the angular aperture; that is, the angle between the extreme rays, which, diverging from the object to the object-piece, pass through it, and arrive at the eye-piece. Object-pieces of two-inch focal length—the lowest power generally used—are constructed with apertures of about 14°, while object-pieces of a quarter-inch focal length are constructed with apertures of 100°, and even of 140°; and with higher powers, apertures of 170° are reached. To comprehend the effect produced by such apertures, it must be borne in mind that the angular aperture of the eye, or angular magnitude of the pencils of rays that enter the pupil from an object at the ordinary distance of distinct vision, is not more than half a degree.

Illumination of Translucent Objects.—The great majority of microscopic objects are translucent in consequence of their tenuity, and to render their translucence more perfect, they are placed on slips of glass, and saturated, with a drop of pure water, if intended merely for temporary inspection, or with Canada balsam, if intended to be preserved as permanent objects. They are next covered each with a small piece of very thin glass, made expressly for the purpose, the thickness in some cases not exceeding the hundredth of an inch, and the

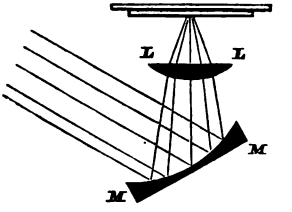
object is ready for temporary inspection. Permanent objects, however, are fixed in their place by gumming paper round the slip of glass, so as completely to envelop it, and cutting out a small circular piece on both sides of the slip, in the centre of it, where the object is placed. The slips of glass, with the objects thus mounted on them, are called *sliders*. They are usually about two inches long and half an inch wide.

The slider containing the object to be examined, is laid upon a stage, s s, the surface of which is blackened, as it is desirable to exclude as much as possible all extraneous light from entering the object-piece, in order to enhance the effect of that passing through it from the object. In the centre of the stage is a circular hole, and the slide is so placed that the object may be over the centre of the hole, which is so arranged as to be in a line with the axis of the microscope.



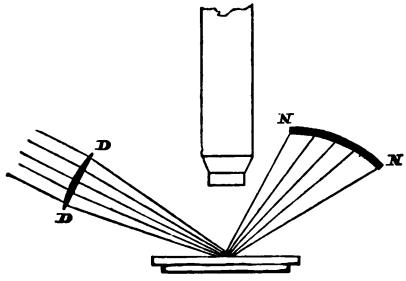
The concave mirror M M, collects the light from the sky (that from a white cloud being preferred), or from a lamp, and concentrates it upon the object, a compound achromatic lens, L L, called the condenser, being interposed, if a greater degree of condensation be required.

To limit the diameter of the pencil of light thus transmitted to the object to agree with the extent of the object, an opaque diaphragm, D D, with holes in it of different sizes, is attached to the underneath part of the stage by a pivot, round which it can be turned, until the condensed light passes to the object through the opening best suited to it. Again a plate of ground glass may be turned round beneath the diaphragm, so as to moderate the intensity of the pencil of light, when it is received on the mirror directly from the sun, or from a very brilliant lamp.

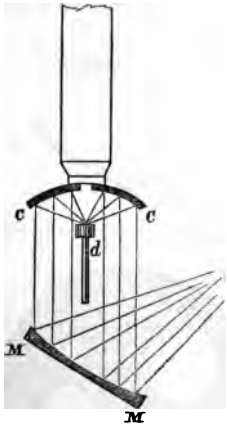


Illumination of Opaque Objects.—Opaque objects may generally be placed on a blackened plate of sufficient size to cover the opening in the centre of the stage, and then illuminated obliquely from

above, by means either of a condensing lens, D D, or of a concave mirror, N N.

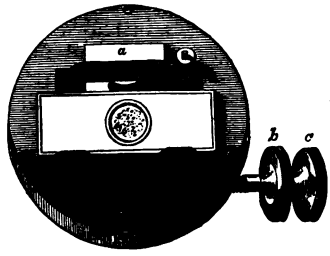


The Lieberkuhn.—With object-pieces of the highest powers, however, these methods are inapplicable, since the object is then so near the object-piece that the light from the lens or mirror would be either wholly, or in great part, intercepted by it. The object is in this case supported in a dark cell, which fits into the opening in the centre of the stage, and intercepts the central rays proceeding from the mirror M M, while it allows the remaining rays of the pencil to pass to a silver cup, C C, called a Lieberkuhn, from the name of its inventor, with a hole in its centre, through which the object end of the microscope passes. By this cup, or concave reflector, the light received from the mirror M M, is condensed upon the object, and strongly illuminates it.



Support and Movement of the Object with Microscopes of High Powers.—In making use of high powers, it is necessary that the stage supporting the object should be perfectly free from all tremor, the slightest motion being so magnified as to prevent a good view from being obtained. It is also necessary that it should have sufficient strength and solidity to bear, without flexure, the pressure of the hands in the manipulation of the *object;* for with the very high powers now attained, the focal

adjustment must be so exact, that a displacement produced by the pressure of a finger, upon a stage having the least elasticity, or not fixed to the instrument with perfect firmness, would throw the object out of focus. At the same time it is necessary that it possess facilities for imparting great delicacy of motion to the object, so as to bring the minutest part of it into view with ease and certainty. For this purpose the stage is made of two or more pieces moving one upon another, so that the object can either be turned completely round, without passing out of the field of view, or can be moved in two directions at right angles to each other by means of micrometric, or fine-motion screws, *b*, and *c*.



White's Lever Movement.—Instead of the two slow motions given by the two micrometer screws, White's lever, by a single motion of the hand, moves the object at once in *any* desired direction. It consists of a lever, D E (Fig. 1), to the shorter arm of which the ball B, is firmly screwed, and moves in a socket, formed by the upper plate of the stage A, and the cap

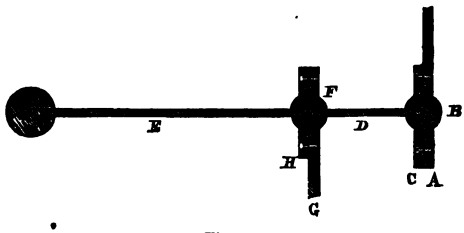


Fig. 1.

C, which is a brass plate secured by two screws. This lever passes through the perforated ball F, moving in a socket formed by the arm G, which is attached to some immovable part of the microscope-stand, and the cap H, similar, and similarly secured, to the cap C, as represented in Fig. 1; the longer arm E, of the lever is nearly three times the length of the shroter arm D; but, when the lever is in use, this proper-

tion is not constant, as will be seen by Fig. 2; for the longer arm of the lever having been elevated, and the shorter one depressed, and the ball B having travelled in a straight line to *b*, instead of in an arc of a circle, it will be found that the shorter arm has increased by a quantity equal to the space between 1 *f* and 2 *f*; and for this reason the ball F is perforated, to enable that part of the lever to move easily, though without shake. As the end of the lever to which the hand is applied moves in all cases in an opposite direction to the ball B; and, as the compound microscope inverts the

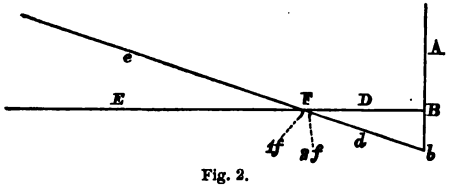


Fig. 2.

image of the object viewed, it follows the object will appear to move in the direction of the hand: moreover, as for each position of the ball B, there is but one in which the other end of the lever can be placed, if a certain portion of an object is seen at any time, and it is required to bring the same part into the field again, this will be done by placing the hand in the original position.

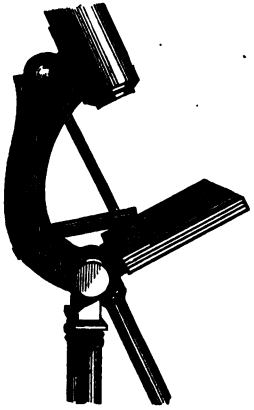


Fig. 3.

This lever may be applied to a stage, whatever be the construction of the guides for its motion. When, however, it is applied to a stage having plates moving horizontally and vertically by means of dovetail slides, it is better to have the upper plate move vertically, in which case the longer arm of the lever and its knob have to balance that plate only; but should the middle or second plate move vertically, then the lever must be sufficiently heavy to support the two plates, when the stage is in the position represented by Fig. 1. Fig. 3 represents White's *lever* applied to a three-plate stage.

Stands for Mounting Microscopes.—The most eminent makers of microscopes, both British and foreign, have devoted their attention to make the mounting of the instrument rival the perfection of its optical construction. Simplicity and portability have been combined with the necessary solidity and firmness, and perfect smoothness and precision in the action of the moving parts.

The amount of labour and skill bestowed on these beautiful instruments necessarily enhances their cost to a degree corresponding with their perfection; but very useful instruments are also manufactured at a very moderate price.

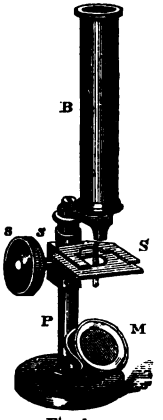


Fig. 1.

The annexed figure (Fig. 1) represents one of the simplest modes of mounting them. P is a vertical pillar rising from a stand of sufficient weight to give the instrument the required steadiness. On the top of this pillar is pivoted a socket, into which the body, B, of the microscope fits. The stage S, is attached to a tube which slides on the pillar, and is fixed in the position desired by a screw *s*, which clamps it to the pillar. The mirror M, at the bottom of the instrument, has a reflector on each side of it, one plane and the other concave, either of which can be turned to face the stage, and placed at any desired angle.

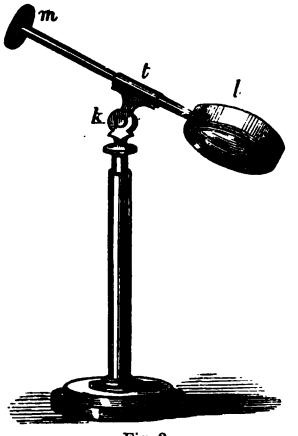


Fig. 2.

For the illumination of opaque objects, a condensing lens, *l*, is made use of: it slides through a tube, *t*, with friction, and can be turned round in it by means of the milled head *m*; and the tube is attached to its supporting pillar by a knuckle-joint, *k*. By these arrangements it is evident that the lens can be brought into any desired position.

In Fig. 3 the instrument is supported on a cradle c c, to which the stage and mirror are also attached, and it

can thus be inclined at any angle that may be most convenient.

Fig. 4 is a cheap form of mounting well adapted for a dissecting microscope. It has a fixed stage firmly supported on three legs, and the condensing lens for illumination of opaque objects is attached to the stage itself. One of the legs is hollow, and the arm which carries the body of the instrument fits into this leg, and is moved up and down by a rack and pinion by turning the milled head *h*, by which means the focus is adjusted for distinct vision of the object.

Fig. 3.

R. and J. Beck's Popular Microscope.—This is undoubtedly one of the best *second-class* microscopes: its construction will be readily understood from the accompanying figure (p. 68). The body, A, which is Wenham's Binocular (p. 57), is carried by a strong arm, B, attached to a square bar, C, that may be moved up or down by a rack and pinion in the tube H, forming the lower part of the stand, to which the stage D, and the mirror E, are attached.

The base F is triangular, and connected with the tube H by a broad stay, G, moving on centres at the top and bottom,

so as to allow this tube, and with it the body of the instrument, to be placed either in a vertical or in a horizontal position, or in a position more or less inclined. In every one

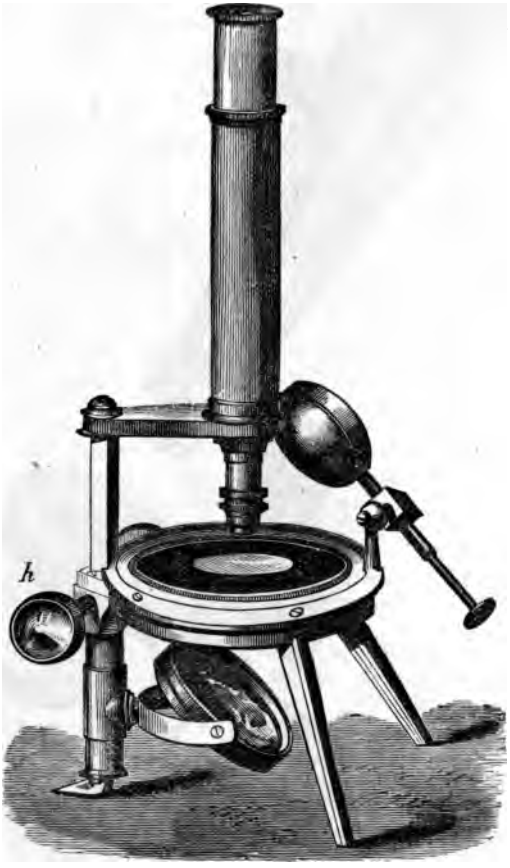


Fig. 4.

of these positions the instrument can be fixed firmly and steadily by fitting the projecting pin at the end of the tube H into one of six holes (one is seen near the stout pin L), of which

four are ranged along the medial line of the base, and the sixth is in the stud K, at the extremity of the base. For a

vertical position the pin is placed in the hole near L, for an inclined position it is placed in one of the holes towards the

extremity of the base, and for a horizontal position it is placed in the hole in the stud K, the inner surface of the stay G then resting on the stout pin L. This is a light form of stand, and yet firm and strong; the instrument cannot shift in the least degree after being placed in any of its positions, and the weight is always well balanced nearly over the centre of the base.

The stage is circular, and consists of a bottom stage-plate, upon which is fitted the stage proper, which consists either of a plain stage, T, or a stage consisting of two plates, with slow-motion adjustment by means of micrometric screws. In either case the stage can be revolved upon the stage-plate, which is concentric with the body, so that the part of the object under examination will always remain in the field of view during the rotation. The object-holder U is provided with a ledge, V, and a light spring, W: it is held to the stage by a spring, so that it can be moved about easily by one or both hands. The small spring W is fastened to the object-holder by a milled head, which will unscrew, so that the position of the spring may be altered, to give more or less pressure upon the edge of the object.

When only a flat surface is required, the object-holder may be removed from the plain stage T, by unscrewing from its under side two small milled heads, which connect the holder to a circular spring; or, by removing the plain stage T, altogether, a simple flat plate may be substituted.

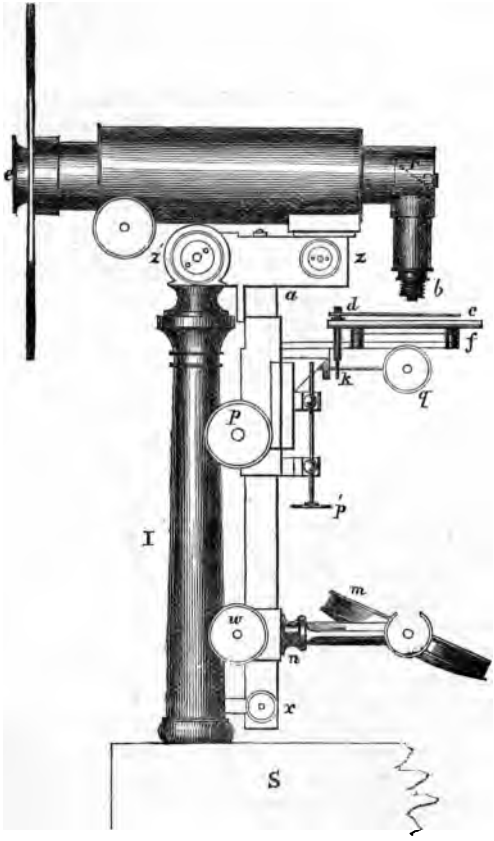
Beneath the stage plate is a cylindrical fitting for the reception of a diaphragm, or any additional apparatus that may be required there.

The mirror E, besides swinging in a rotating semicircle, will slide up and down on the tube H, and it will turn on either side for oblique illumination.

The object is focused by turning the milled head O, which gives a quick movement to the body of the instrument; and then the milled head P acts upon a lever which gives a very delicate motion to the body, and perfects the adjustment with great nicety.

Charles Chevalier's Universal Microscope.—This instrument, intended for all kinds of microscopic observation, is represented in the accompanying figure on a scale of one-fourth its natural size. The objective is at *b*, the eye-piece at *e*. The pencils of light by which the object is seen, rise at first vertically; but, being totally reflected at the hypothenuse of

the prism *r*, they are turned back horizontally towards the eye-piece, an arrangement which enables the observer to take a convenient position, either for prolonging his observations



or for making drawings of the magnified images presented to his view (p. 79).

The objective is composed of two or three achromatic lenses whose focal lengths are from eight to ten millimeters;* they

* *That is,* from about ·355 in. to about ·394 in.

are marked with the numbers 1, 2, 3. No. 1 can be used alone, or No. 1 and No. 2 can be used together, taking care to screw No. 1 first to the body of the instrument, and then No. 2 upon No. 1; or No. 1, No. 2, and No. 3 may be all used together, taking care to screw No. 1 first to the body, then No. 2 on to No. 1, and, lastly, No. 3 on to No. 2. In the first case we have the least magnifying power, and the object is placed at the greatest distance from the objective; in the second, the magnifying power is higher and the object nearer; and in the third, the magnifying power is higher still, and the object is brought very close to the objective.

With each combination of the object-lenses there can be used any one of six eye-pieces, numbered 1, 2, 3, 4, 5, and 6. The four first are Huyghenian eye-pieces (p. 52), and 5 and 6 are simple magnifying glasses of very short focal length.

The instrument is supported on a pillar I, firmly screwed into the stand S, which also forms the case for packing away the instrument when not in use; the body of the instrument is attached to this pillar by the intervention of the arm $s\,s'$, represented in the figure in a horizontal position, and two knuckle-joints at s and s'.

At right angles to the arm $s\,s'$ is attached a bar $a\,x$; and, when the instrument is in the position represented in the figure, the lower end of the bar fits into a piece projecting from the pillar, and is fixed by the pin at x. The bar $a\,x$ has a rack on the face next the pillar, and on the bar are two brass boxes n and t, to one of which is attached the mirror, and to the other the stage.

The mirror is moved up or down by means of the pinion w: it has a concave reflector on one side, and a plane reflector on the other, and can be set with either side upwards, and inclined at any desired angle, since it moves on two pivots at the extremity of a diameter.

The stage c has a course adjustment by means of the pinion p working in the rack on the bar $a\,x$, and a fine adjustment by the slow motion screw p', to set the object on the stage in exact focus. The piece d, which moves up and down with friction, serves to hold the objects on the stage, and to press them when necessary. Underneath the stage is the diaphragm f, and below this again a plate of ground glass, which can be turned to intercept and moderate the light when received directly from the sun, or from a very strong lamp.

The upper plate of the stage is pushed forward or drawn

back by the slow-motion screw *k*, and moved to the right or left by the slow-motion screw *q*. By these two motions the whole extent of the object can be passed before the view without losing sight of the image.

These screws, *k* and *q*, move at each complete turn through a very small and very accurately-determined distance, and have, moreover, their heads divided on the circumference, so as to note the number of turns, and fractions of a turn, that are required to pass an object from one side to the other of each of two micrometric threads, fixed, at right angles to each other, to the diaphragm of the eye-piece, which is at the exact place where the real image of the object is formed. The actual size of the object is thus determined.

To place the microscope in a vertical position, unscrew the prism, place the objective in the prolongation of the body, and turn this round the knuckle-joint *s*. Again, by drawing out the pin at *x*, and turning the instrument round the second knuckle-joint *s'*, the limb *s s'*, can be inclined to any extent, or rendered vertical, and the body of the instrument be thus inclined at any angle between the horizontal and vertical, the stage at the same time moving, and taking a position always at right angles to the tube. Lastly, to arrange the instrument for the examination of chemical objects, turn round the piece *b r*, which is connected with the body by a bayonet-joint, till it points vertically upwards. A second stage and mirror for illumination is to be adapted to it in this position. A watch-glass placed on the stage holds the solution to be examined, and the evaporation does not injure the objective.

There are three patterns of *first-class* microscopes manufactured in this country — the Ross microscope, Messrs. Powell and Ireland's microscope, and Messrs. R. and J. Beck's microscope. In the first and third, the instrument is supported by two uprights rising from a triangular base; in the second it is supported on a tripod; and in all three it turns upon two centres, about which it is so nicely balanced as to rest with equal steadiness at whatever inclination it may be placed.

In the Ross pattern, and in that of Messrs. Powell and Ireland, the piece to which the centres are attached consists of a square box, terminating at the bottom in a cylindrical tube for carrying the mirror, and the body is inserted in a ring at the end of an arm, which fits over a pivot on the head of a square bar that slides in the square box, and is moved in *or out by a rack* and pinion acted on by a milled head. This

arrangement allows the arm to be turned on the pivot away from the stage, by which the latter and also the bottom of the object-piece can be got at and cleaned, or the object-piece itself can be changed with the greatest convenience. The arm also furnishes a lengthened space for a lever, by which the fine adjustment for focusing is made.

In R. and J. Beck's pattern, the part to which the centres are attached is carried up in one solid piece to a bed nearly the whole length of the body, upon which the latter rests, and along which it is moved by a rack and pinion, acted on by a milled head.

This arrangement does not allow the body to be moved from over the stage, nor for the delicate fine adjustment does it furnish a space equal to that in the patterns of Ross and Powell and Lealand; but these advantages are fully, if not more than fully, compensated by the steadiness of the support given to the body of the instrument, and consequent removal of all tremor from it, of which the slightest amount is injurious when its effects are magnified by the highest powers. Another advantage is the easy and even motion of its quick adjustment, while in the other patterns, the rod carrying the arm and body of the instrument must necessarily be made to slide with great stiffness in the box that rests on the centres.

The frontispiece to this volume represents a *first-class* binocular microscope, with the most recent improvements. The stage has a complete rotating motion, concentric with the axis of the microscope, worked by rack and pinion, as well as motions in two directions, at right angles to each other. The underneath part of the stage is shown, fitted with the iris diaphragm.

ACCESSORIES OF THE MICROSCOPE.

Numerous accessory instruments, besides those already described, are used with the microscope for variety and perfection of illumination for the exhibition of particular phenomena, and for holding objects of various kinds.

Direct Illumination of Transparent Objects. — To view transparent objects by means of light directly transmitted through them, either the concave mirror attached to the microscope is made use of, or the light is reflected from a mirror, or a rectangular prism, through an achromatic condenser. In either case the light must be brought to a focus at the place of the object, in order that the rays may continue their

course as though diverging from points of the object. Now, with object-pieces of four-tenths of an inch focal length, and with lower power, the light is generally in excess; and since this cannot be remedied by altering the position of the mirror or condenser without impairing the distinctness of the image, recourse must be had to the diaphragm. The degree of light best suited for an object depends upon the degree of its transparency; and, consequently, it is generally desirable to try several of the holes in the diaphragm, some of which have stops in the middle shutting off the central rays of the pencils, and examine the effect produced in each case. To facilitate the operation, each hole, when concentric with the body of the instrument, is stopped by a weak spring. A great improvement, however, consists in continuously examining the object while the amount of light thrown on it is gradually varied. This is effected by a diaphragm with shutters, which by a screw action can be more or less closed; and the best form of such a diaphragm is *Brown's Iris Diaphragm*, in which the number of shutters is numerous, and the circular form of the aperture is consequently preserved during their expansion or contraction.

Oblique Illumination of Transparent Objects.—In many cases the structure of transparent objects is but imperfectly shown by rays thrown directly through them, and it becomes important to view them by oblique rays, traversing them either from all sides, or from one side only, and then passing through the object-piece; or it may be desirable to illuminate them so obliquely, that none of the illuminating rays shall pass through the objective, but that the image shall be entirely formed by rays irregularly reflected from the object, as though it were opaque, in which case it appears as an illuminated object on a dark ground: this is called dark-field illumination. To give oblique illumination on one side, the mirror attached to the microscope below the stage is mounted on a double arm, and the stage is made very thin. Another mode is by a prism, which reflects and condenses the light at the same time.

The Spot Lens.—To give oblique illumination on all sides, a plano-convex lens of great convexity is made use of, the central portion of which is covered by a circle of black varnish, so that only the peripheral rays pass through, and fall obliquely on the object; or a condenser of considerable aperture is employed, in which the central rays are stopped out in a similar manner.

Wenham's Parabolic Reflector.—The most perfect method of giving to the illuminating rays an obliquity so great that none of them shall pass directly on to the object-piece, is the intervention of the parabolic reflector.

Fig. 1 represents this instrument, the paraboloid being set in a tube, A, with a milled edge, B, for adjusting it, to focus on the object the light reflected from it. This form of setting is adapted for applying it to Beck's Popular Microscope: the form of setting must, however, be varied to suit the appliances of the stage to which it is to be attached.

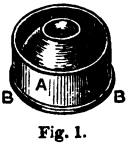


Fig. 1.

Fig. 2 represents a section of the paraboloid in its full size. C is the base, and A and B are the parabolic sides of the section,

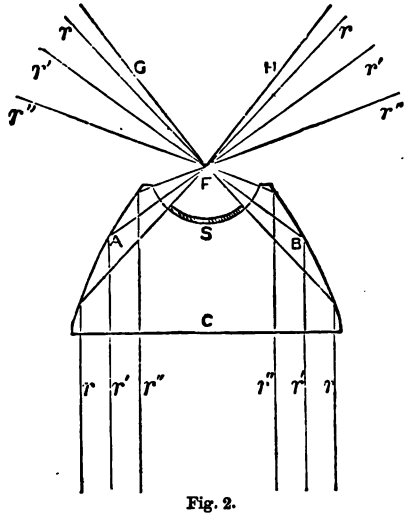


Fig. 2.

the apex being cut off to make a passage for the rays of light *r*, *r'*, *r''*, to the object, and a stop, S, being placed in the aperture thus formed, to prevent any rays from passing through direct to the object-piece. The light must be thrown upon the parabolic surface A and B in rays parallel to the axis of the parabola, and will thus be reflected to the focus F of the parabola, which must be adjusted upon the object. *The object-piece lying* entirely within the angular space G F H,

which admits no rays direct from the reflector, can, therefore, receive only the rays irregularly reflected from the object.

As the rays of light are to be thrown upon the reflector in parallel pencils, a plane mirror or prism must be used to reflect the daylight upon it; but, if the source of light be a lamp sending forth divergent pencils, these must be converted into parallel rays, either by the interposition of a condenser between the plane mirror and the parabolic reflector, or by direct reflection from a concave mirror. In either case the parallelism of the rays may be tested by placing a card or piece of white paper over the base c of the paraboloid: this should be equally illuminated over its whole surface.

Oblique Illumination of Opaque Objects.—The most perfect illuminator for the oblique illumination of opaque objects on one side only, with object-pieces of low power, is *Beck's Parabolic Illuminator.* It is fitted on to the object-piece by a ring clip, and reflects the light, which is thrown upon it

horizontally, down upon the object placed upon the stage. The ring clip is of course adapted to fit the object-pieces with which it is intended to be used; but Mr. Crouch has constructed a holder for this illuminator, by means of which it is attached to the body of the microscope, and can be used with any object-piece whatever.

Oblique Illumination of Opaque Objects on all Sides is afforded by the Lieberkuhn, already described; and by throwing the light from the mirror upon the Lieberkuhn in an oblique direction, oblique illumination of the object on one side only *may also be obtained* with object-pieces of high powers; or

this result may be arrived at by covering one half of the Lieberkuhn with a non-reflecting substance—such as black paper. The disadvantages of the Lieberkuhn are that in order for its focus to agree with the distance from the object-piece to which the object must be brought, to be in the focus of the microscope, every different object-piece must have its own Lieberkuhn; and that the size of the objects which can be submitted to inspection with it, is limited by the necessity of allowing sufficient space beyond them for the passage of the light from the reflector to the Lieberkuhn.

Beck's Patent Illuminator.—The direct illumination of opaque objects under high powers, is effected by Beck's Illuminator, in which the light is thrown down upon the object through

Fig. 1.

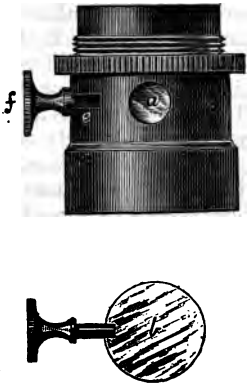


Fig. 2.

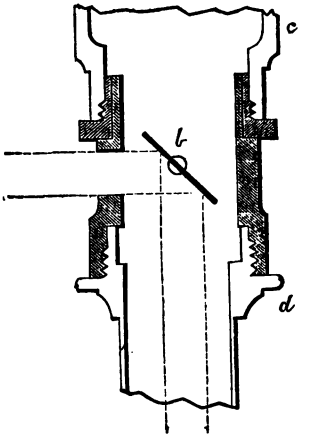


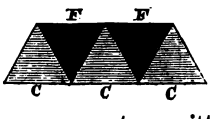
Fig. 3.

the object-piece itself. This object was first accomplished by a small metallic reflector, introduced into the body above the object-piece; this, of course, intercepted the central portion of the light returned from the object. Powell and Ireland substituted for the metallic reflector a plate of polished glass, which allowed the principal portion of the central rays from the object-piece to pass through it, and Mr. R. Beck further improved the instrument by using for the reflector a disc of very thin glass, which reflects more light than a polished surface.

Fig. 1 represents the instrument of its full size; Fig. 2 gives

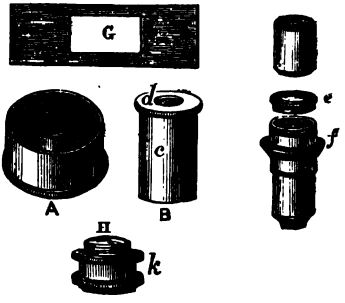
a sectional view of it, screwed into its position on the bottom, *e*, of the body of the microscope, and having the object-piece, *d*, screwed into itself; and Fig. 3 represents the disc, *b*, of thin glass, which forms the reflector. This reflector is introduced into the tube which adapts it to the microscope, through the slot *e* (Fig. 1), until it comes opposite the aperture, *a*, through which the light is admitted; when it is stopped by a shoulder on the stem to which it is attached; the milled head *f*, then serves to set it at any desired inclination. It is manifest that, by slightly varying the inclination, the rays reflected from the disc *b*, can be made to pass either through the centre of the object-piece, or through a portion of it more or less on one side; and thus the illumination of the object can be rendered either direct, or more or less one-sided and oblique.

Sorby's Spectroscope Eye-piece. — The increasing use of spectrum analysis, as a means of investigating the ultimate constitution of bodies, has led to the invention of this instrument for the comparison of the spectra formed by different substances. In the place of the ordinary diaphragm or stop of the Huyghenian eye-piece, is inserted a stop with a narrow slit in it, and in front of the eye-glass is placed a tube containing five prisms, two of flint and three of crown glass, in passing through which the light, admitted through the narrow slit, is refracted into a spectrum, and thus the spectra, formed by transmitting light through different substances placed on the stage of the microscope, can be observed; or the light may pass through the microscope direct from the mirror, and be refracted into the ordinary solar spectrum. To compare the spectrum thus formed, with a second spectrum, formed by light from another source, or transmitted through a different substance, a right-angled prism is placed so as to cover half the slit, and the light is reflected by a mirror through a tube, containing the substance whose spectrum is to be examined, and into the prism, by which it is reflected upwards, so that a portion of it passes through the half slit over the prism side by side with a similar portion of the light from the object-piece through the other half of the slit, and thus two spectra are formed side by side, whose slightest differences can be most accurately distinguished.



Polarizing Apparatus.—Most beautiful and brilliant results are obtained by viewing many microscopic objects with the

assistance of polarised light; some objects which, when illuminated by ordinary light are scarcely visible, appear in the most varied and vivid colours under the influence of polarised light; and much knowledge is obtained by this means, of the structure of some substances, which could be arrived at in no other way. The peculiar property called polarisation may be imparted to light by various peculiar modes, both of reflection, and refraction; but the most simple apparatus to apply to the microscope for this purpose, is the following:—A prism, called a Nicol's Prism, of double refracting crystal, arranged so as to transmit only one portion of each refracted ray, forms the polariser A, and is fitted so that it can be turned round underneath the stage: and another prism, denominated the analyser, exhibits the peculiar effects of the polarised light after transmission through the substance under examination by it. This prism, mounted in a short tube, *e*, screws into the place of the back stop of the object-piece *f*, and the object-piece together with the prism, is attached to the nose-piece of the body of the microscope by the adapter H, which has a revolving fillet, *k*; or the short tube *e*, with the prism enclosed, may be screwed into an outer tube *c*, and then, having the cap *d*, screwed in over it, forms the piece B, which both slides and revolves in the place of the cap of the eye-piece. When the analysing prism is thus placed over the eye-piece, the field of view is contracted; and, when it is placed immediately above the object-piece, the definition is somewhat impaired: its position must, therefore, be regulated by the consideration of which of these defects is of the most importance in the examination of the particular object under view. G is a plate of selenite for the exhibition of colours arranged in a variety of beautiful forms.



The Camera Lucida.—One of the most beautiful and useful applications of the camera lucida is its adaptation to the compound microscope, by means of which minute details and lineaments of objects are depicted with a precision and fidelity only surpassed by photography.

The microscope being placed in a horizontal position, the camera is fixed upon the eye-piece in place of its ordinary cap. When Wollaston's camera (p. 15) is made use of, the observer, looking upon it, sees the object by reflection, and the paper, placed on the table beneath it, directly, and the distance being so arranged that the object appears clearly delineated on the paper, an accurate drawing of it can be traced.

Since, in estimating the magnifying power of microscopes, it is usual to take ten inches as the distance of most distinct vision, it is advantageous to have the paper at this distance from the eye, and if the paper and pencil point are not clearly seen in coincidence with the image of the object, when the paper is thus placed, a lens is brought round under the prism, to produce the desired effect.

When Amici's camera (p. 18) is used the operator, looking in a horizontal direction, views the object directly, and the paper and pencil by reflection.

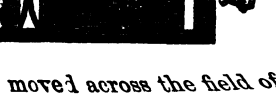
There is a knack in the use of either form of the instrument only to be acquired by practice, and the microscopist must not be discouraged by the failure of his first attempts, but persevere, until he can avail himself thoroughly of the great advantages to be derived from the use of this instrument.

The Stage Micrometer.—The stage micrometer is a glass slider having upon it, in the usual place for the object, lines ruled at the distances of 100ths and 1000ths of an inch. Being placed upon the stage, and having its image drawn on a sheet of paper at a distance of ten inches from the eye, the magnifying power of the microscope is determined by comparing the sketch thus made with an ordinary scale ruled into inches and tenths of an inch. Thus, if three divisions, at 1000th of an inch apart, occupy, when marked on the paper, a distance of $\frac{6}{10}$ of an inch, the magnifying power would be 200. Again, the micrometer being replaced on the stage by any object, and the image of this object being thrown by the camera lucida on the same paper on which the enlarged view of the micrometer has been delineated, the actual size of the object will be determined.

The Eye-piece Micrometer.—The most accurate means of measuring the dimension of an object is afforded by the eye-piece micrometer. Any errors in the accuracy of the divisions of the stage micrometer are multiplied by the whole power of *the microscope;* but in the eye-piece micrometer they are *multiplied by the* magnifying power of the eye-glass only.

The eye-piece micrometer was at first placed by Mr. Andrew Ross in the focus of the positive eye-piece; but, more recently, it has been adapted to the Huyghenian eye-piece. In its most perfect form, denominated the cobweb micrometer, it consists of two parallel threads passing across the diaphragm of the eye-piece, one of which is fixed, and the other is moved across the field by turning a screw with a circular head. The distance between the threads of the screw is 100th of an inch, and the rim of the circular head of the screw is divided into 100 equal parts, and, when turned, passes by a fixed index, so that a motion of the interval between two adjacent divisions, past this index, corresponds to a variation in the distance between the parallel cobweb threads of the 10,000th of an inch. A portion of the aperture of the diaphragm is cut off by a comb at right angles to the thread, the distances between the teeth of the comb being the same as those between the threads of the screw. To measure an object by this micrometer, one of its boundaries must be brought into contact with the fixed thread, and then, by turning the circular head, the other thread is to be moved until it comes into contact with the opposite boundary; the number of teeth of the comb that have been passed by will then show the complete number of turns of the screw, and the number on the circular head opposite the index will show the number of 100ths of a turn, that have been required to pass the thread across the whole breadth of the object. The value to be attached to the indications of this instrument must be determined by means of the stage micrometer; thus, if three complete turns and five 100ths of a turn be required to move the thread over the magnified image of the space between two adjacent lines on the stage micrometer, ruled at 1000th of an inch apart, a complete turn of the screw will indicate an actual dimension in the object of $\frac{1}{3030}$ of an inch, and a motion of one of the divisions on the circular head past the index, will denote a distance of $\frac{1}{303000}$ of an inch.

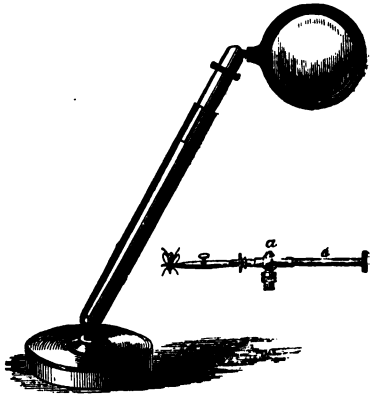
This form of micrometer is necessarily expensive, and a much cheaper form is Jackson's eye-piece micrometer, which consists of a thin plate of glass, ruled with lines like the stage micrometer, but set in a frame, so that when placed in the eye-piece in the focus of the eye-glass, it can be moved across the field of



view by turning a screw with a milled head, against which it is held by a spring. Every tenth line is ruled longer than the others, and one of these being brought into contact with one boundary of the object, the number of divisions between this and the opposite boundary gives the breadth of the object. When the breadth of the object does not occupy an exact number of divisions, a mode of estimating, with a great degree of accuracy, the parts of a division, beyond an exact number, contained in the breadth, is afforded by a line ruled across the divisions, and thus forming a diagonal scale (vol. i. p. 24).

The actual value of the divisions must be determined, as in the cobweb micrometer, by means of the stage micrometer; and in both cases it is advisable to eliminate the errors of the latter by taking the mean of several measurements on different parts of it.

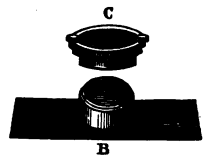
Stage Forceps.—The stage forceps serve to hold objects, and



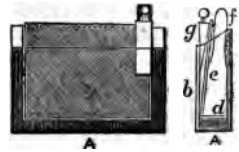
to turn them about in various directions. They are closed by a spring, and opened by pressing against a pin. They are attached to a short arm, which fits on a pin at some part of the stage, or object-holder; and by pushing the stem *b*, through the ring *a*, at the end of the arm, and turning it round in the ring by the milled head at the end of the stem, while the entire instrument is revolved upon the pin on which it fits, the object can be brought into any desired position whatever.

A very convenient form of mounting for a condensing lens, to illustrate opaque objects, is also represented in this figure.

The Live Box.—In the live box, B, the object is confined between the glass, *a*, of the lower part, and that of the cap, C: the distance between them can be varied by sliding the latter more or less on. As the thin glass is only dropped into a slight recess in the top of the cap, and held there by the heads of two screws, it can easily be taken out for wiping, or replaced by another when broken.



The Glass Trough.—This trough, A, is used for exhibiting objects in water, and must be adjusted with its thin plate of glass, *b*, in front. The object may be confined by placing a piece of glass, *e*, diagonally in the trough, its lower edge being kept in its place by a strip, *d*, at the bottom; then, if the object introduced be heavier than water, it will sink until stopped by the sloping plate. To regulate more particularly the position of the object, a very slight spring, *f*, may be applied behind the diagonal plate, and an ivory wedge, *g*, introduced in front of it, and pushed down to any desired extent.



USE AND TESTING OF THE MICROSCOPE.

The Light.—The best position for the light is on the left of the observer, leaving his right-hand free to attend to the adjustments of the instrument without any danger of intercepting the illumination.

If daylight be made use of, that proceeding from a window whose aspect is away from the position of the sun should be selected; so that reflected, and not direct, solar rays should be made use of. The best light of all is that reflected in this manner from a white cloud. For artificial light, that from a wax or Palmer's candle may be used, if protected by a glass chimney to keep it steady; or a good oil or paraffin lamp, or an Argand gas-burner. If any of these artificial sources of illumination be used, they should be at a distance of between ten and twelve inches from the microscope, and means should be provided for raising and lowering the light, and for shading it from the eye.

Care of the Eyes.—In using a monocular instrument, the unemployed eye should be kept open, and, though at first some confusion is caused by the two distinct views thus pre-

sented to the two eyes, the power is soon acquired of regarding mentally only the view of the microscopic image. The constant use of the same eye is also injurious, and the young microscopist should therefore accustom himself to use either eye with equal facility, and employ them alternately. No expedients, however, with the monocular instrument can enable it to be used with the same amount of comfort and freedom from fatigue as the binocular, which is now, therefore, almost universally employed for general purposes; and in particular cases, when the whole of the light is required to be concentrated on a single image, the binocular, as now constructed, is converted into a monocular instrument by the simple withdrawal of the binocular prism or prisms.

Opaque Objects Uncovered.—In viewing opaque objects illuminated by light thrown upon them from one side, whether by a condenser or reflector, the light necessarily falls upon them very obliquely, and, consequently, if they were covered with glass, a great part of the light would be reflected from the surface of the glass. Such objects, therefore, should always be uncovered, when presented for examination.

The terms lower powers and higher powers have been on several occasions employed by us in speaking of object-pieces; and we shall need them again in discussing the properties of a good microscope, and the modes of testing them. It will, therefore, be advisable to state that by lower powers we mean object-pieces having focal lengths not less than half an inch; by medium powers, objectives with focal lengths less than half an inch, and exceeding one-sixth of an inch; and by higher powers, objectives having focal lengths of one-sixth of an inch and less.

Quality of Object-pieces.—There are four attributes to be considered in judging of the character of an object-piece:—(1.) The Defining Power; (2.) The Penetrating Power; (3.) The Resolving Power; (4.) Flatness of Field.

1. *Defining Power.*—This consists in showing well marked the principal features of the object, and especially its boundaries. This power depends upon the completeness of the corrections, and is an essential quality of every good objective. It is somewhat impaired by extending the aperture. It is to be tested by using a deep eye-piece, and still further by pulling out the draw-tube.

2. *Penetrating Power.*—This consists in the power of seeing *clearly not merely the* points of the object which are exactly *in focus, but also points* somewhat in advance of the focal

distance, or retired beyond it, and is essential to the examination of any object having inequalities of surface, or markings that penetrate to different depths. The penetrating power is inversely proportionate to the angle of aperture, and, consequently, in those object-pieces that are designed for a view of an object in its entirety, the angular aperture must not be too far increased. The disadvantage arising from excessive aperture, and the consequent want of penetration, is more especially felt when using the stereoscopic binocular instrument. Not only is the distinct view limited to a small depth, but the exaggeration of the stereoscopic effects (p. 33) by a large aperture must also be considered an imperfection.

3. *Resolving Power.*—This consists in the power of separating, and distinguishing, the finest and most delicate details of an object. It is only to be increased by increasing the angle of aperture, and is, consequently, inconsistent with great penetrating power, which is inversely proportionate to the aperture. The large apertures conferring this power should, therefore, only be bestowed on the higher powers, for which the task of resolving with the highest degree of perfection, may be reserved, while to the lower powers is allotted more especially that of correct definition and penetration.

4. *Flatness of Field.*—This quality, again, is not so important with the higher powers, intended to view the details of an object in succession, as with the lower powers, used for forming a correct view of its entire form and structure. It practically depends to a considerable degree on the extent of the field of view; and, consequently, the comparison of this quality in different object-pieces must be made with the same eye-piece.

For testing the completeness of the corrections, and the perfection of the centerings, a minute globule of mercury, called an artificial star, is made use of. Minute globules of mercury are spread on a black cloth, and the light from a window, reflected from one of them, is brought into focus in the centre of the field of view. The image thus formed should appear as a very small disc, free from colour, with the exception of a very pale green tint. Then, varying the position of the eye-piece, by drawing out and pushing in the draw-tube, the object should present the same appearances, at the same distances within and beyond the correct focus, and the disc in either case should enlarge concentrically.

A good test for defining power is afforded by the pollen *grains of the* hollyhock, viewed as an opaque object, and

showing minute spines. A deep eye-piece should be used, which will exaggerate want of definition.

For resolving power, one of the best test-objects is afforded by the scales of the *Podura plumbea*, or skiptail, a small wingless insect, the size of a flea, found in damp cellars. These scales should appear covered with a great number of delicate marks, like notes of admiration.

For *testing flatness of field*, good objects are sections of wood, viewed with eye-pieces to give a field of from nine to twelve inches.

Care of the Instrument.—In using the higher powers, in which the object-piece is very close to the stage, great care should be taken not to bring it in contact with the object; and, when either the object, or the object-piece is changed, the body should be moved away from over the stage, in those instruments admitting of this arrangement, or should be raised well above the stage by means of the rack and pinion for quick adjustment.

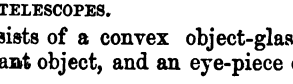
The glasses of the eye-piece may be unscrewed and wiped, when necessary, with a piece of soft chamois leather, from which the dust has been well beaten out, and the outside surfaces of the objective may be also wiped in the same manner; but the objectives of English manufacture, when requiring to be unscrewed, must be sent to the manufacturer, who alone will be able to reset them without impairing their perfection. When only a little dust is on any of the glasses, it is best to remove it by a smart puff of the breath, and then to evaporate the moisture, deposited on the surface, by moving it briskly, backwards and forwards, through the atmosphere, as wiping, even with the softest material, will in time impair the high polish to which the surfaces are brought.

CHAPTER VI.

TELESCOPES.

REFRACTING TELESCOPES.

The Refracting Telescope consists of a convex object-glass, which forms an image of a distant object, and an eye-piece of one or more lenses, which performs the office of a microscope for viewing this image. The *most simple* form of the tele-



scope is that called the *astronomical telescope*, and consists of

two convex lenses, the object-glass *o*, of as great focal length, and, consequently, low magnifying power, as the size of the telescope will permit, and the eye-glass *e*, of small focal length and, consequently, high magnifying power. When arranged for distinct vision of a distant object, the distance between the two lenses is equal to the sum of their focal lengths: an inverted image *i*, of the object is consequently formed in the common focus of the two lenses, and the pencils proceeding from the image consist, after refraction at the eye-glass, of parallel rays, which are the most favourable for distinct vision.

The magnifying power of this instrument is represented by the ratio of the focal length of the object-glass to that of the eye-glass, and may therefore be increased either by increasing the focal length of the object-glass, or by diminishing that of the eye-glass. The latter means, however, cannot be resorted to without increasing both the chromatic dispersion, and the spherical aberration. Hence, before the means were discovered of forming achromatic and aplanatic object-glasses, the only unobjectionable way of increasing the power of the telescope was by increasing the focal length of the object-glass, and astronomers used to attach the object-glass to the end of a long pole. This contrivance was called an aërial telescope. Huyghens used one of 123 feet in length, and Cassini one of 150 feet.

That the field of view should be as bright as possible, the image of the object-glass, formed by the eye-glass at the place of the eye, should not be larger than the pupil of the eye; and the brightness will then vary directly as the square of the diameter of the object-glass, and inversely as the square of the magnifying power. The brightness is also diminished by passing through the refracting media; and hence it is always an object to employ as few lenses as possible, consistently with the attainment of the other requisites of a good telescope.

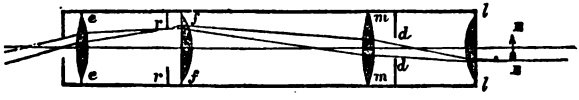
Refracting telescopes for astronomical purposes are now constructed with achromatic object-glasses, and either Huyghenian or Ramsden's eye-pieces; these eye-pieces, however, when applied to telescopes, are called *celestial* eye-pieces.

The Huyghenian eye-piece is to be preferred, when we are only seeking to obtain the best defined and most distinct view of an object, and is the best eye-piece for all reflecting telescopes; but when it is necessary to place cross-wires or spider-lines at the place of the image in the field of view, for the purpose of accurately measuring the position of an object, at the time of observation, or to apply an apparatus, called a micrometer, for measuring the dimensions of an image, Rams-

den's positive eye-piece is employed. With either of these eye-pieces the object appears inverted, which is no inconvenience when this object is one of the heavenly bodies; it is for this reason they are called celestial eye-pieces.

For the convenient observation of stars near the zenith, a plane reflector or prism is placed in the eye-piece, by which the directions of the pencils are turned, so that the axis of the eye-lens is at right angles to the axis of the instrument. Such an eye-piece is called a *diagonal eye-piece.*

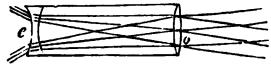
When terrestrial objects are to be viewed, it is generally necessary that they should appear erect, for which purpose the inverted image formed by the object-glass must be again inverted by the eye-piece. The *terrestrial* or *erect* eye-piece, used for this purpose, is, in fact, a compound microscope, consisting of an object-lens, *l l*, a diaphragm, *d d*, an amplifying lens, *m m*, a field-lens, *f f*, and eye-lens, *e e*, the two latter forming either a negative or positive eye-piece, having the usual diaphragm at the place of the formation of the erect image. The pencils of rays from the inverted image of a



distant object formed by the object-glass of the telescope at E F, pass first through the object-lens, *l l*, of the eye-piece, crossing the axis of the instrument near the diaphragm *d d*, and thence passing through the amplifying-lens *m m*, form an image at *r r*, a second time reversed, and therefore erect, either before or after passing the field-lens *f f*, as the eye-piece is positive or negative; and this erect image is viewed, of magnified dimensions, through the eye-lens *e e*. An inspection of the figure in which the passage of a pencil from one extremity of the inverted image E F, to its exit from the eye-lens, is indicated, will show how the diaphragms, *d d*, and *r r*, cut off the extreme rays, which would not be sufficiently freed from spherical and chromatic aberration.

In consequence of the loss of light consequent upon this construction, portable telescopes with celestial eye-pieces were formerly much used by navigators for descrying objects at night, and these telescopes were, consequently, called night-*glasses.* They are now almost superseded by the great improvements which have been made in the binocular Galilean telescope, or double opera-glass.

By substituting for the convex eye-lens of the astronomical telescope a concave eye-lens of the same focal length, a simple telescope is formed with only two lenses, which shows objects erect. This is called the *Galilean telescope*, and is the construction used for opera glasses. When arranged for distinct vision of a distant object, the object-glass and eye-lens are separated by a distance equal to the difference of their focal lengths. The pencils of light proceeding from the object, after refraction at the object-glass *o*, tend to form an image of the object in the common focus of the two lenses; but, being intercepted by the concave eye-lens *e*, their rays are rendered parallel, and, consequently, adapted to produce distinct vision to an eye placed behind this lens.



The magnifying power, as in the astronomical telescope, is represented by the ratio of the focal length of the object-glass to that of the eye-lens.

Great attention has been paid to this class of telescope during the last twenty or thirty years. They are made of the binocular form; that is, two telescopes combined together, one for each eye, the focus being adjusted by a screw and rack, which moves the eye-glasses of each telescope simultaneously. The object-glasses and eye-glasses are both compound lenses, forming achromatic combinations; and when made of the best quality, and larger in size than the ladies' opera glass, they are denominated race-glasses, or field-glasses, or rifle-glasses, according to the fancy of the manufacturer.

Messrs. Parkes and Son, of Birmingham, have two very fine glasses of this kind. One of them is fitted with twelve glasses, that is, each of the eye-glasses and object-glasses is composed of three pieces, forming a very perfect achromatic combination; and from this circumstance, and the beautiful quality of the crystal from which they are formed, I have seen nothing to surpass them in brightness, clearness, and distinctness of definition. The other is a Patent Tourist's Binocular, with three different magnifying powers; in fact, there are three eye-glasses in each telescope, which may be used successively by turning a milled head. The first adjustment contains a pair of tinted crystal lenses, and gives a *power of 4½* diameters; the second gives a power of about

6½ diameters; and the third gives a power of about 9½ diameters, which is the highest practicable power attainable. The object-glasses are triple, and 2½ inches in diameter; and the eye is protected from the irritation and fatigue produced by heat, by a pair of accurately-ground pebbles fitted in front of the eye-glasses. This is altogether a very superior instrument, and in dull or misty weather is as powerful a telescope as can be used with advantage for the observation of terrestrial objects.

In clear bright weather telescopes may be used having magnifying powers of from 10 to 40 diameters, the highest powers being only attainable when a large object-glass is used; but it must be borne in mind that whatever magnifies terrestrial objects, will also magnify the mist or other imperfections of the terrestrial atmosphere, through which they are seen. On the other hand, the Binocular Galilean Telescope enables a person to use both eyes in viewing objects, and, by transmitting to them a much greater amount of light from these objects, than they would otherwise receive, renders the objects brighter, clearer, and more distinct. The light from the objects is in fact caught upon the comparatively large object-glasses of the binocular, and transmitted to the eye, instead of the much smaller amount of light which would otherwise be caught by the pupil of the eye itself. The Binocular Galilean, as has been already stated above, is found to make the best night-glass, for viewing terrestrial objects by moonlight or in the twilight, from the very large amount of light that they transmit to the eyes.

For viewing terrestrial objects in bright weather, telescopes with erect eye-pieces are most advantageously used with powers varying generally from 15 to 25 diameters. Higher powers than this are not advantageous, unless the object-glasses be of extra size, or the weather unusually clear and bright. Telescopes are, however, constructed with eye-pieces of variable powers, so that the highest can be used upon objects that are brightly illuminated, and the lower powers in dull weather or for objects in shadow. Such eye-pieces are called *pancratic*.

It has already been stated that the erect eye-piece is in fact a compound microscope, consisting of an object-piece formed with two lenses and a diaphragm, and an eye-piece formed also of two lenses, and also generally containing a *diaphragm*. *Now the* object-piece and eye-piece are usually

fitted into the opposite ends of a single tube, which slides in the tube carrying the object-glass of the telescope, and is pushed in or out to adjust the focus for distinct vision. In this form the magnifying power of the telescope is absolutely fixed; but if the eye-piece be fixed in one draw-tube, and the object-piece in another, so that the distance between them can be varied, while the focus can be re-adjusted by moving both together nearer to or further from the image formed by the object-glass, we have the *pancratic* eye-piece, which is analogous to the microscope with movable eye-piece or object-piece, in which the power can be considerably varied. The advantage of this arrangement is that a glass can be constructed, whose lowest powers shall be good for all ordinary occasions, while on favourable occasions a power may be used, which could only otherwise be obtained by telescopes with larger object-glasses, and of a more expensive character.

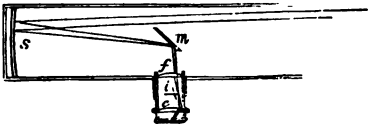
Many improvements have been made in the construction of terrestrial eye-pieces, the points aimed at being increase of extent, and luminosity, of the field, and more perfect achromatism. Several glasses have been forwarded to us, which for their size and price have attained these requisites to a remarkable degree, and our attention has been particularly called to a new achromatic eye-piece,* which, with an increase of magnifying power, gives also, what is unusual with such increase, a *more luminous and extended* field, combined with a remarkably clear and sharp definition. We have tested it, by trying it, and a good eye-piece of the ordinary construction, with the same telescope-body and object-glass.

REFLECTING TELESCOPES.

Since the discovery of the methods of forming achromatic and aplanatic object-glasses, the magnitude and available magnifying powers of refracting telescopes are theoretically unlimited; but the difficulty of procuring flint glass of even texture and free from flaws, in pieces of any considerable magnitude, has hitherto practically placed a limit upon the magnitude and available power of refracting telescopes. By the substitution, however, of reflectors, which are always achromatic, for the object-glasses, telescopes of colossal magnitude have been most successfully constructed. Of reflecting telescopes there are four kinds—the Newtonian, the Gregorian, the Cassegrainian, and the Herschelian.

* Forwarded by Messrs. Parkes.

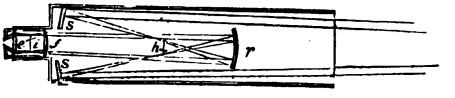
The Newtonian Telescope consists of a concave object-speculum, *s*, a reflecting prism, or plane reflector, *m*, making



an angle of 45° with the axis of the telescope, placed between the object-speculum and its focus, and an eye-piece. The pencils of light proceeding from a distant object tend to form an image after reflection at the object-speculum, but are bent by the plane reflector, or prism, so that the image is formed at *i*, on the axis of the eye-piece, and in the focus of the eye-lens.

Nasmyth's Telescope is a combination of the Newtonian telescope and of the Cassegrainian telescope described below. The rays reflected from the concave object-speculum are received either upon a small speculum or prism placed in the axis of the tube, between the object-speculum and its focus. By this they are turned at right angles, and form an image in a tube inserted in one of the trunnions upon which the instrument turns. Into this tube also the eye-piece is inserted. The advantage derived from this arrangement is, that while the great tube is moved round in a complete circle, if necessary, the tube, in the trunnion, containing the eye-piece, remains fixed; and the observer can survey the whole meridian, or other circle in the heavens, without changing his position.

The Gregorian Telescope consists of a concave object-speculum, *s*, a small concave-speculum, *r*, whose focal length is short compared with that of the object-speculum, and an eye-

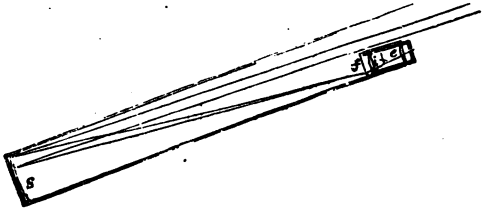


piece. The small speculum is placed so that its focus is near the focus of the object-speculum, but a little further from this speculum. The pencils of light proceeding from a distant object, after reflection at the object-speculum, form an inverted image, *h*, of the object at the focus of this speculum, and after reflection again at the small speculum form a second image, *i*, inverted with respect to the former, and, consequently, *erect* with respect to the object.

This telescope has, for terrestrial purposes, the advantage over the Newtonian telescope of showing objects erect, but yields to it both in the brightness and perfection of the image, because the second mirror increases the spherical aberration produced by the first, and it is extremely difficult to give the mirrors the proper curvature to remedy this evil.

The Cassegrainian Telescope consists of two specula and an eye-piece, like the Gregorian; but the second speculum is convex instead of concave, and is placed between the object-speculum and its principal focus, at a distance from this focus somewhat less than its own focal length. The pencils of light proceeding from a distant object, after reflection at the object-speculum, tend to form an inverted image of the object, but are intercepted, before doing so, by the convex speculum, and made to form the image, still inverted, in the focus of the eye-lens. Objects, therefore, are still inverted; but the spherical aberration of the convex speculum being opposite to that of the concave object-speculum, the whole spherical aberration is diminished. This telescope is also shorter than the Gregorian. It is, however, inferior to the Newtonian telescope for celestial observations, and not well adapted for terrestrial purposes on account of the inversion of the object.

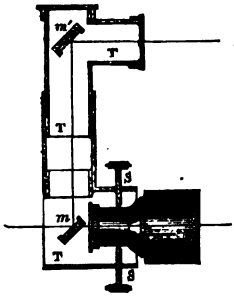
When light is reflected at a mirror or speculum, there will always be a waste and dispersion; and in consequence of the two reflections, and also of the light intercepted by the plane mirror, or second speculum, the loss of light in all the reflecting telescopes hitherto described is considerable. Sir W Herschel, by a very simple contrivance, obtained what is called



the front view; but this construction is only applicable to instruments of very large dimensions. In the Herschelian telescope the axis of the object-speculum *s* is slightly inclined to the axis of the tube, and the image *i*, being thus thrown to one side of the tube, is there viewed by the eye-piece.

ADJUSTMENT AND TESTING OF TELESCOPES.

Pouillet's Method of Determining the Magnifying Power of a Telescope.—It has been stated above that the magnifying powers of astronomical and Galilean telescopes may be deduced from the focal lengths of the lenses of which they are composed; but the results thus obtained are only approximate, and in fact the focal lengths of the lenses themselves are not always accurately known. Direct, accurate, and simple means of determining the magnifying power are therefore desirable. The following is the method adopted by Pouillet. At fifty or sixty yards distance a staff is set up, marked with white and black divisions, to which the telescope is directed: the bent tube T, containing two plane mirrors *m* and *m'*, is fitted on to the eye-piece of the telescope, and held there steadily by the screws *s*, *s*; the mirror *m* is pierced with a small hole about the twelfth of an inch in diameter; looking through this hole, the magnified image of the staff is seen in the telescope, while the staff itself is also seen by rays proceeding from it to the mirror *m'*, reflected thence to the mirror *m*, and thence to the eye. These two images are easily made to coincide with one another, and the number of the natural divisions overlying one of the magnified divisions, expresses the magnifying power of the telescope: thus, if fifty-three of the natural divisions overlie three of the magnified divisions, the number overlying one magnified division is seventeen and two-thirds, and this is an accurate measurement of the magnifying power of the telescope.



We shall now proceed to explain the best methods of adjusting and testing telescopes, as given by Pearson in his valuable work on Practical Astronomy.

Methods of Adjusting and Testing Refracting Telescopes.—Let us suppose that we have a refracting telescope of $3\frac{1}{2}$ feet focal length, and $3\frac{1}{4}$ inches aperture. Then, *to test the object-glass*, lay the tube of the telescope in a horizontal position upon some fixed support about the height of the eye, and place a printed card vertically, but for a celestial eye-piece *in an inverted* position, against some wall or pillar at thirty

or forty yards' distance, so as to be exposed to a clear sky; then, when the telescope is directed to this object, and adjusted by the sliding tube for distinct vision, the letters on the card should appear clearly and sharply defined, without any colouration or mistiness; and, if very small points appear well defined, the object-glass may be deemed a pretty good one for viewing terrestrial objects. If the glass be intended for astronomical observations, fix at the same distance a black board, or one-half of a sheet of black paper, and a circular disc of white paper, about a quarter of an inch or less in diameter, upon the centre of the black ground; then having directed the telescope to this object, and adjusted for distinct vision, mark with a black-lead pencil the sliding eye-tube, at the end of the main tube, so that this position can always be known; and if this sliding-tube be gradually drawn out, or pushed in, while the eye beholds the disc, it will gradually enlarge and lose its colour, till its edges cease to be well defined. Now, if the enlarged misty circle is observed to be concentric with the disc itself, the object-glass is properly centered, as it has reference to the tube; but, if the misty circle goes to one side of the disc, the cell of the object-glass is not at right angles to the tube, and must have its screws removed, and its holes elongated by a rat-tailed file, small enough to enter the holes. When this has been done, replace the cell, and examine the disc a second time, and a slight stroke on the edge of the cell by a wooden mallet will show, by the alteration made in the position of the misty portion of the disc, how the adjustment is to be effected, which is known to be right when a motion in the sliding tube will make the disc enlarge in a circle concentric with the disc itself. When, then, the disc will enlarge so as to make a ring of diluted white light round its circumference, as the sliding tube holding the eye-piece is pushed in, or drawn out, the cell may be finally fixed by the screws passing through its elongated holes. When the object-glass is thus adjusted, we can proceed to ascertain whether the curves of the respective lenses composing the object-glass are well formed and suitable for each other. If a small motion of the sliding tube of about one-tenth of an inch from the point of distinct vision, in a 3½-feet telescope, will dilute the light of the disc and render the appearance confused, the figure of the object-glass is good; particularly if the same effect will take place at equal distances from the point of good vision, when the tube is

alternately drawn out and pushed in. Such an object-glass is said to be aplanatic. A telescope that will admit of much motion in the sliding tube without affecting sensibly the distinctness of vision will not define an object well at any point of adjustment, and must be considered as having an imperfect object-glass in which the spherical aberration is not duly corrected. The achromatism of the object-glass is to be judged of by the absence of colouration round the enlarged disc. When an object-glass is free from imperfection both in respect of its aplanatism and achromatism, it may be considered a good glass for all terrestrial purposes.

How far an object-glass is good for astronomical observations can only be determined by actual observation of a heavenly body. When a good telescope is directed to the Moon, or to Jupiter, the achromatism may be judged of by alternately pushing in and drawing out the eye-piece from the place of distinct vision; in the former case a ring of purple will be formed round the edge; and, in the latter, a ring of light green, which is the central colour of the prismatic spectrum; for these appearances show that the extreme colours, red and violet, are corrected. Again, if one part of a lens employed have a different refractive power from another part of it, that is, if the glass, particularly flint glass, be more dense in one part than another, a star of the first or even of the second magnitude will point out the natural defect by the exhibition of an irradiation, or what opticians call a wing at one side, which no perfection of figure or adjustment will banish; and, the greater the aperture, the more liable is the evil to happen.

Another method of determining both the figure and quality of the object-glass is by first covering its centre by a circular piece of paper, as much as one-half of its diameter, and adjusting it for distinct vision of a given object, which may be the disc above mentioned, when the central rays are intercepted, and then trying if the focal length remains unaltered, when the paper is taken away, and an aperture of the same size applied, so that the extreme rays may in their turn be cut off. If the vision remains equally distinct in both cases, without any new adjustment for focal distance, the figure is good, and the spherical aberration cured; and it may be seen, by viewing a star of the first magnitude successively in both cases, whether the irradiation is produced more by the extreme or by the central parts of the glass; or, in case one half of the *glass be faulty* and the other good, a semicircular aperture,

by being turned gradually round in trial, will detect what semicircle contains the defective portion of the glass; and, if such portion should be covered, the only inconvenience that would ensue would be the loss of so much light as is thus excluded.

The smaller a large star appears in any telescope, the better is the figure of the object-glass; but, if the image of the star be free from wings, the size of its disc is not an objection in practical observations, as it may be bisected by the small line by which the measure is to be taken. When, however, an object-glass produces radiations in a large star, it is unfit for the nicer purposes of astronomy. In testing a telescope, if a glass globe be placed at 40 yards' distance when the sun is shining, the speck of light reflected from this globe forms a good substitute for a large star, as an object to be viewed.

Whenever an object-glass is under examination, it will be proper to have the object examined by it in the centre of the field of view; and, when an object-glass is tested for astronomical purposes by the methods described above, it is necessary to employ a good negative eye-piece, which generally gives a better field of view than the positive.

If any fringes of red or yellow are observed on the edges of a white disc placed on a black ground, when the telescope is adjusted for distinct vision, and the disc carried too near the edges of the field, this species of colouration indicates that the *eye-piece* is not sufficiently free from spherical aberrations; and, if the curves of the lenses are suitable for each other, the cure is effected by an alteration in the distance between them, which must be finally adjusted by trial with a good object-glass.

Methods of Adjusting and Testing Reflecting Telescopes.— To adjust the specula of a Cassegrainian or Gregorian instrument, procure a Ramsden's eye-piece, which will render an object visible in the compound focus of the two lenses of which it is composed; then hold this eye-piece in front of the Huyghenian eye-piece of the telescope, and, by varying the distance, find the position in which the image of the large speculum is seen, well defined through both eye-pieces, and, if the image of the small speculum is seen precisely on the centre of the large one, the metals may be considered as rightly placed; but, if not, the proper screws must be used in succession, till the required position is determined. When the face of the large metal stands at right angles to the length of the tube, the adjustment may generally be finished without disturbing it; and, when the bed that receives it has once

been properly finished, it will be advisable not to alter it, unless some accident should render such alteration indispensable.

To try whether the figures of the metals are adapted for each other: let the instrument be directed to some luminous point, as a white disc on a black ground, or, what is better, to a star: then having adjusted for distinct vision, firstly observe if the disc or star is well defined, and free from irradiations; secondly, carrying the small speculum short distances beyond, and short of, the place for distinct vision, examine if the disc or star enlarges alike in similar changes of position: if the result be satisfactory, the metals may be considered as well placed, and well adapted for each other.

To try whether the large speculum partake of the parabolic form, let the aperture be partially covered, first at the central part, and then round the circumference, by tin, pasteboard, or stiff paper; and if on trial the same adjustment for distinct vision be good in both these cases, and also when the speculum is all exposed, the figure may be considered good. If these effects be not produced, the instrument will be incompetent to perform several of the nicer observations in astronomy. When a mistiness appears in the field, it is a proof that the aberrations are not corrected, and that the figure of at least one of the specula is not perfect.

If a telescope is not good with its full aperture, its effect may be greatly improved, by putting a cover on the mouth, with a circular aperture, of about one-half the diameter that the tube has, in such a way that the diminished aperture may fall entirely at one side of the opening of the tube.

MOUNTING TELESCOPES.

For general purposes telescopes of moderate power are used by holding them in the hand, and they may be carried about in leather cases, fitted with straps for slinging them from the shoulders. Telescopes of moderate power are very extensively used at sea, and it is evident that from the rolling and pitching on the waves no stand could be of any use on board ship.

On land, a tripod stand forms a very simple mounting, and for telescopes of considerable power, stands with mechanical appliances for directing the telescope, may be employed. The accompanying illustration represents such a form of mounting. The handle H, is connected by a universal joint *f*, with an endless screw *e*, which acts upon a rack, attached to the pillar supporting the telescope, and turns the whole instru-

ment round; it is raised or lowered by turning the milled heads S, S, which move in and out, one tube sliding within another. When the field of view of the telescope is small, in consequence of the high power of the telescope, a small telescope F, of lower power, is attached to it, the axes of the two telescopes being parallel. This small telescope is called the

finder, and when an object is brought into the centre of its field of view, it will also be seen in the field of view of the larger telescope.

The methods of mounting telescopes for particular purposes belong to the consideration of surveying and astronomical instruments, and will be described in Parts V. and VI., in the third volume.

CHAPTER VII.

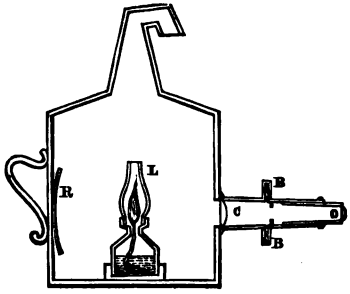
INSTRUMENTS FOR EXHIBITING MAGNIFIED PICTURES OF OBJECTS TO AN ASSEMBLAGE OF SPECTATORS.

In the microscope and telescope (Chapters V. and VI.) the images of objects formed by a convex lens or combination of lenses, have been confined within a tube, and viewed by an eye-piece; but by the omission of the eye-piece, and the employment of a screen to receive the image, a picture is formed which can be viewed at once by a whole assembly of spectators.

THE MAGIC LANTERN.

The magic lantern is an instrument for exhibiting on a screen an enlarged view of pictures painted on glass with transparent colours.

It has already been explained (p. 22), that when an object is placed at a distance from a lens greater than its focal length, a real image of this object is formed on the other side of the lens. When the object is at a distance from the lens equal to twice its focal length, the magnitude of the image is equal to that of the object; and as the object is moved nearer and nearer towards the principal focus, the magnitude of the image is increased more and more, to an unlimited extent. The extent to which the magnifying power may be made available is, however, limited by the amount of light which can be thrown on the object, and by the indistinctness arising from the spherical and chromatic aberration, which increases with the magnification of the image.



In its simplest and cheapest form the magic lantern consists of a dark lantern, with a bent chimney, to carry off the smoke and heated air with no emission of light.

Within the lantern a lamp L, with an Argand burner, is placed, to give a powerful light; behind the lamp is a reflector, R, to increase the illumination; and in front of it, and on a level *with its* flame, is a tube, in which is fixed a large plano-convex

lens, c, to condense the light upon the picture, which slides through a groove, B B, formed upon the tube. The tube is continued beyond the groove carrying the picture, and in it is fitted a second tube, sliding in and out like the draw-tube in the body of a microscope, or the eye-tube in a telescope. In this tube is set another plano-convex lens, o, to receive the light radiated from the picture painted on the slide, and transmit it, to form an enlarged picture on a screen at an appropriate distance from the lantern. The position of the lens o, is so adjusted that the slide is just beyond its principal focus B, when the tube that carries the lens is pushed in as far as it will go. In this position the picture on the screen will be enlarged to its greatest extent, and its imperfections and want of brightness will also be the greatest; but by pulling out the draw-tube, and at the same time advancing the lantern nearer to the screen, the magnification will be diminished, while the brightness and distinctness will be increased; and after a few trials the operator will soon find the position that best suits his purpose.

The body of the lantern should be large, that it may not become inconveniently heated; the best oil should be burned; and the glass chimney of the lamp should be as tall as the lantern will permit.

The larger the picture painted on the slide, the less the magnification that will be required, to produce a picture of a given magnitude on the screen, and, consequently, the brighter and more perfect this picture will be.

There are two modes of exhibiting the pictures on the screen, and the construction of the screen must be suited to the mode intended to be adopted. One mode produces effects the most brilliant and distinct, the other the most illusory and amusing.

In the former, the lantern is placed in front of the screen, along with the spectators; and the picture is seen by the light projected from the lantern, and irregularly reflected from the screen.

The object in this case is to *avoid transparency* in the screen, as all light passing through the screen would be a loss to the picture, transmitted to the eye by reflection. The best screen in this case is made of strong white paper, pasted on canvas, and fixed on a stretching frame.

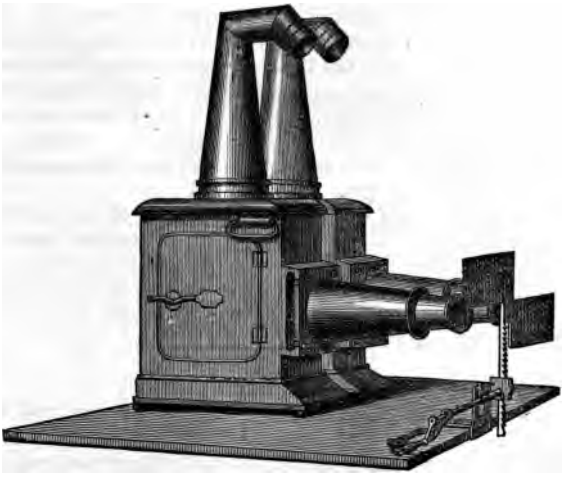
Phantasmagoria.—In the other mode of using it, the instrument is *placed on* the opposite side of the screen, to that

occupied by the spectators. The screen in this case must be semi-transparent, and may be made of white muslin, or fine calico, stretched upon a frame, its transparency being increased by wetting it well with water.

The object of this arrangement is to produce an optical illusion, termed *phantasmagoria*, or the meeting of phantoms. The exhibitor and his apparatus being concealed from the spectators, the lantern is first placed close to the screen with the draw-tube drawn out as far as it will go, and a very small picture is thus formed on the screen. The exhibitor then moves the lantern slowly back from the screen, pushing in the draw-tube at the same time, so as to keep the focus of the projected rays upon the screen; the picture in consequence grows larger and larger; and the figures represented upon it, consequently, appear to approach the spectators, and to be actually coming into the midst of them. At length the exhibitor keeps the large and apparently near figures stationary for a brief period, and then reverses his former movements, until, the lantern being again close to the screen, the figure is apparently lost in the distance. At this moment he changes the slide without attracting the notice of the spectators, and proceeds to the production of a fresh illusion in the same manner.

Dissolving Views.—The concealment of the mode of operation is always an element of the interest produced by exhibitions of this kind, and another mode of disguising the change of slides, and, at the same time, of introducing highly entertaining effects, is that adopted in the production of dissolving views. For this purpose two similar lanterns are placed side by side, so as to throw pictures of exactly the same magnitude upon the same part of the same screen; to the front of the stand, upon which the lantern is placed, a box is attached, through which passes a bar that carries two shutters; on this bar a rack is formed, which is acted on by a pinion turned by a winch; and the shutters are so arranged that, when by one of them the nozzle of one of the lanterns is completely closed, the light from the other is entirely unobstructed, and *vice versâ*. A slide containing a picture being introduced into each of the lanterns, when the shutters are in this position, it is manifest that only one of the pictures will be exhibited on the screen. The winch being then turned slowly, the nozzle of the lantern containing this picture is gradually closed, while the nozzle of *the other lantern* is as gradually opened; the picture first

exhibited grows fainter and fainter, and changes into the picture projected from the second lantern, which grows stronger and stronger until it is shown with the fullest brilliancy, and the picture first exhibited is entirely shut out. The slide containing this picture is then changed for another,



which is in like manner made to supersede that last exhibited; and in this manner a series of pictures may be made to glide from one into the other, to any extent that may be desirable.

A very pleasing effect is produced by exhibiting in this manner a summer scene changing into the same scene in its winter dress, an interior by day merging into the same brilliantly illuminated at night, &c.

The Oxy-hydrogen Light.—When it is desired to exhibit very large pictures before a public audience, the increased magnification requires a good achromatic combination of lenses, and a more intense illumination, than can be yielded by an ordinary lamp. The most brilliant artificial light that could be produced, before the discovery of the electric light, was the oxy-hydrogen, or Drummond light; and this was the light used for the illumination of dissolving views on a large scale at various exhibitions in London and elsewhere. This light is given off from a ball or cylinder of lime, heated to a

white heat by the combustion of hydrogen and oxygen gases, supplied from two pipes, in the proportions in which they combine, to form water.

The Oxy-calcium Light.—The apparatus for the production of the gases, and for their application to the lantern, is expensive, and from the explosive nature of the hydrogen, its manipulation is attended with considerable danger in inexperienced hands. The oxy-calcium light is produced by forcing a jet of oxygen through the flame of a spirit-lamp, and placing a ball of lime so that the deflected flame may impinge upon it. This is a much more economical light than the oxy-hydrogen; its use is entirely unattended with danger; and the brilliancy of the light is constant and but little inferior to that of the oxy-hydrogen.

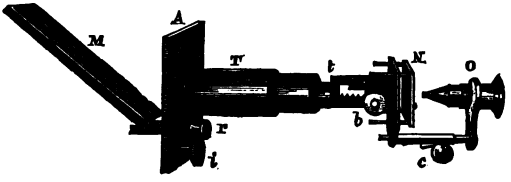
The Electric Light.—The most brilliant of all artificial lights, produced by the passage of a voltaic current from one to another of two charcoal points, has been applied to the magic lantern by M. Dubosc of Paris: and by throwing it into two lanterns, by means of two reflectors, it has been adapted to the exhibition of dissolving views.

THE SOLAR MICROSCOPE.

The solar microscope, by which effects are produced that may be reckoned among the most interesting and instructive of optical phenomena, consists of two distinct parts—a reflector and system of lenses, for strongly illuminating the object to be represented; and a combination of lenses, in which the chromatic and spherical aberrations are nicely counterbalanced, and a flat field produced, for the purpose of projecting a greatly magnified picture of the object upon a screen. It may, in short, be described as a magic lantern with the sun for an illuminator, and a compound object-piece for the more perfect projection of the image.

The Illuminating Apparatus.—A is a square copper plate, to one side of which the tube T, is attached, and on the other side is the mirror M; this plate screws on to a square board, not shown in the figure, which has a hole in the centre corresponding with the opening through the plate A, into the tube T. The mirror can be set at any inclination by turning the milled head *i*, and can be moved round into any desired position, by turning the milled head *r*, attached to a pinion that works upon a circular rack, formed on the plate A. The *light reflected from* the mirror M, is directed upon a large con-

densing lens, set in the larger end of the tube T, so as to pass through this lens in the direction of its axis: it is thus converted into a convergent pencil, proceeding along the tube T, into the smaller tube *t*, at the extremity of which it traverses a small focussing lens, and is thrown with a greater degree of convergence upon the object, placed upon a slider, which



passes between two plates, N, held together by spiral springs. The tube *t* slides within the tube T, and affords the means for a rough adjustment to produce the desired degree of condensation on the object, and the milled head *b* serves to set the object with greater accuracy, so that the whole of it may be evenly and strongly illuminated.

In condensing the rays, proceeding from the sun, directly upon the object, not only is the light condensed, but the heat also; and, consequently, many objects would soon be seriously injured or destroyed. This inconvenience is to be obviated by the interposition of a medium, which is pervious to the sun's light, but impervious to its heat. Water possesses the desired property to a considerable degree, and is rendered almost completely impervious to heat by dissolving in it as much alum as it is capable of holding in solution. A cell, terminated by two parallel plates of glass about an inch asunder, and filled with a saturated solution of alum, is placed between the condensing apparatus and the slides; by this means the whole of the heat is kept back, while the light intercepted is altogether inconsiderable.

Amplifying Apparatus.—The objects for a magic lantern can be painted of a considerable size, so that the magnification required to exhibit them, is very much less than that necessary for minute microscopic objects; and again, the extreme accuracy of delineation required in the latter case, can be dispensed with in the former. A comparatively inexpensive apparatus will, therefore, suffice even for the best description of magic lantern; but for the microscope a combination of

lenses, producing a flat field freed from chromatic and spherical aberrations, is indispensable.

This combination of lenses, or *compound objective*, is mounted in a brass ring *o*, so that its optical axis shall coincide with that of the illuminating apparatus; and, by turning the milled head *c*, it can be moved to or from the object, so as to adjust the focus to the distance of the screen, upon which the image is to be projected.

With the microscope the plan of showing the image through a transparent screen is very objectionable. The screen, therefore, should be quite opaque. Stout white paper pasted on canvas, or a smooth surface of plaster of Paris, will answer the purpose well.

The greater the distance at which the screen is placed, the greater the magnification of the object. It is not desirable, however, to push the amplifying power of the instrument too far; in that case the illumination becomes inconveniently faint, and the smallest amounts of uncorrected aberration perceptibly impair the result.

Method of Adjusting and Using the Instrument.—In a room of sufficient magnitude, a window must be selected, whose aspect will allow the sun's rays to be reflected in the direction of the axis of the tube. This window must be furnished with a shutter having an opening in it, as large as that in the plate and board to which the microscope is attached, and the board must be screwed to this shutter, so that the openings shall correspond, and admit a pencil of light to the large condensing lens, of a diameter fully equal to that of the lens itself. The mirror will thus be outside the shutter, while the microscope projects horizontally into the room; and in front of it the screen must now be placed in a vertical plane at right angles to the axis of the instrument. A distance of ten or twelve feet from the nozzle of the microscope will generally be found sufficient for the production of a clear, and sufficiently enlarged, image upon this screen. The room must next be rendered as dark as possible by closing the shutters, stopping up all interstices, and drawing the curtains, if the windows be provided with them.

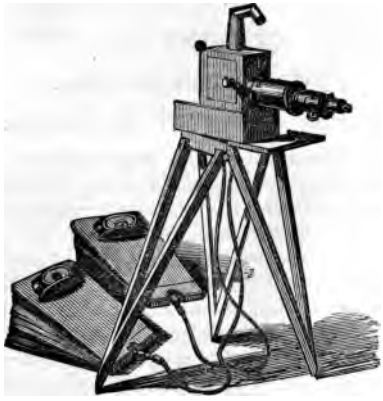
These preliminaries having been arranged, remove the plates N, and vary the position and inclination of the mirror M, by turning the milled heads *i* and *r*, until a uniformly illuminated disc appears on the screen; then, by sliding the *tube t in the tube* T, a position will be found, in which this

disc will be the most clear and distinct. Now, replace the plates N, and insert between them an object; adjust for focus by turning the milled head *c*, and for illumination by the milled head *b*, and a distinct image of the object upon a large scale will be seen upon the screen.

If the exhibition be continued for any considerable time, the position of the mirror must be occasionally altered, to suit the changed position of the sun; this is to be effected, as at first, by turning the milled heads *s* and *r*.

THE OXY-HYDROGEN AND PHOTO-ELECTRIC MICROSCOPES.

The chief inconvenience of the solar microscope is its dependence upon sunshine for illumination, so that it can only be used on fine sunshiny days, and then only during a limited number of hours, in which the sun is in a favourable position.



The invention of the *oxy-hydrogen light* supplied a means of illumination sufficiently intense for the microscope, and thus rendered it independent of the sun. The manner in which this light is produced has already been explained (p. 104); and the accompanying figure shows the manner in which the oxygen and hydrogen gases are supplied from gas bags. The microscope itself, which is here seen attached to the lantern, consists of condensing lenses, for concentrating the illumination upon the object, and a compound objective, for projecting its image on the screen, in all essential particulars

identical with the same parts of the solar microscope, already described.

A still more perfect instrument has been produced by the substitution of the *electric*, for the *oxy-hydrogen* light. Great skill and ingenuity have been employed in order to counterbalance the gradual wasting of the charcoal points, and keep them by a self-regulating apparatus always at the same distance from one another, so as to ensure continuity and uniformity of illumination. These contrivances, however, belong to the domain of electricity and magnetism, and are foreign to the subject of this work: the optical instrument, the microscope, remains still identical with the solar microscope, the source only of the illumination being altered, and not the manner of its condensation, or the objective for the projection of the image.

CHAPTER VIII.

THE CAMERA OBSCURA.

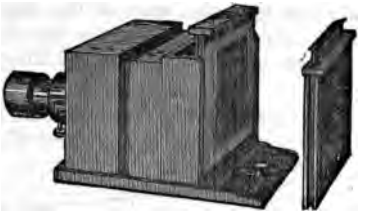
COPYING OF PLANS BY PHOTOGRAPHY.

THE *Camera Obscura* bears the same relation to the *magic lantern* and its microscopic variations, that the *telescope* bears to the *compound refracting microscope:* pencils of light, from objects more or less distant, are brought to a focus by an objective of large diameter; and the picture thus formed, instead of being viewed by an eye-piece, as in the telescope, is projected on a screen, as in the magic lantern, and solar and cognate microscopes already described.

If the distance between the objective and the screen of the camera be regulated to the focus, and the objective be directed to some object, the image of the object will be seen clearly defined on the screen in a reversed position. The image may be reinverted by the introduction of a prism, and extraneous light must be shut out from the screen, so that it receive only that proceeding from the object. If the camera be set up in the neighbourhood of a well-frequented thoroughfare, we have then an agreeable succession of distinct and vividly coloured pictures, differing from finely executed paintings only by exhibiting the actual motions of the objects viewed, men walking, horses trotting, soldiers marching, *banners streaming*, and foliage shaking in the breeze.

The camera obscura was always an instrument of great utility in the arts of design, since by it the process of drawing was reduced to that of mere tracing; but by the discovery of the photographic art, its use has been extended to a most unparalleled extent.*

The form of camera used for photography is most simple; but great care and expense is lavished upon the production of lenses, to give the most accurate results. The lens or lenses are set in a tube at the end of a rectangular box, in which another rectangular box slides, to produce a rough adjustment for focussing. A finer adjustment can then be attained by a slow motion, a screw and rack acting on the tube



containing the lenses. The picture is first received on a plate of ground glass, inserted in grooves at the end of the rectangular sliding-box, and, after adjusting the focus, until the picture thus formed is satisfactory, the ground glass is removed, and replaced by the surface prepared to receive the photographic impression.†

The wonderful accuracy of photography in copying every minute detail, without the slightest strain on the hand or eye of the operator, gives it an immense advantage over the pantagraph or eidograph, and has led to its adoption by Sir H. James for the reduction of the maps and plans of the Ordnance Survey.

The only purpose for which the use of the pantagraph has been retained is for the reduction of plans to so small a scale, that it becomes necessary, firstly, at the sacrifice of truth,

* See also "A Popular Treatise on Photography, the Stereoscope, and Photographic Optics, from the French of D. von Monckoven." By W. H. Thornthwaite, price 1*s.* 6*d.* WEALE SERIES.

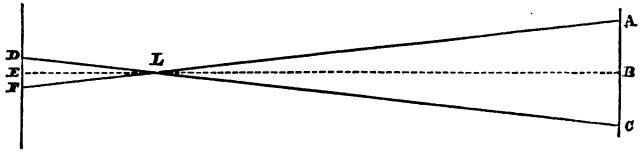
† For description of improved cameras and lenses see "A Treatise on Optics, or Light and Sight theoretically and practically treated." By E. Nugent, C.E. Second Edition, price 5*s.* Strahan and Co.

to enlarge such details as, were they drawn to scale, would be so minute as to be unintelligible, or fail to strike the eye; and secondly, to omit some details in order to avoid confusion.

We proceed to give, from a document compiled for the information of the officers entrusted with the superintendence of the Survey of India, an account of the methods employed at the Ordnance Survey Office, Southampton, for the reduction of plans by photography

APPARATUS USED FOR REDUCTION OF PLANS.

The reduction of plans from larger to smaller scales, is regulated by the law that the scale of the image formed by the lens is to the scale of the plan, as the distance of the image from the lens is to the distance of the plan from the



lens: that is to say, L being the lens, A C the plan, and D F the image; D F is to A C as E L to L B. It would be only necessary, therefore, when reducing plans from one scale to another, to place the lens in such a position that the distances E L and L B should be to one another as the scales.

Various circumstances modify this law as applied to the lenses actually used. Those which the photographer has principally to deal with, when working with the best achromatic lenses, are spherical aberration and curvature of the image. When reducing plans, these influencing causes are of particular importance. The usual remedy is to place a stop $4\frac{7}{8}$ inches in front of the lens, and $\frac{1}{4}$ inch in diameter, which has the effect of diminishing the curvature to the extent of rendering it inappreciable.

The curvature increasing very rapidly with the obliquity of the pencils, there is a limit to the size of the plan which can be reduced from one scale to another without sensible distortion; and there is also a limit to the size of the image *which can be* taken free from sensible distortion. The largest

plans reduced measure 38·016 inches by 25·344 inches, and no negative is taken of a greater size than 9 inches by 6 inches. When the reduction is not so great in degree as to allow of the whole plan coming within these limits, it is subdivided by pencil lines into rectangles, such that, when reduced, they shall occupy the area of 9 inches by 6 inches on the negative, and each rectangle is photographed separately, and the prints mounted together afterwards.

In practice the operation resolves itself into adjusting the camera so that the image, as seen on the ground glass, shall occupy the area which the plate to be photographed should, when reduced to the smaller scale. In order that this may be done, a rectangle is ruled on the ground glass of the camera, representing the area the plans should occupy when reduced to the smaller scale, and the plan and camera are so adjusted that the margin lines of the image of the plan lie exactly on the lines ruled on the ground glass.

As each plan successively photographed cannot well be fixed on the board in exactly the same place, and as the reductions are required to be made in different proportions, it is necessary to provide mechanical contrivances, to enable the operator to adjust each plan to be photographed both rapidly and accurately.

The following are the arrangements, which are found to answer remarkably well:—

The camera is made of mahogany, strongly bound with brass, and is provided with an endless screw to adjust the focal distance. The construction is shown in the Figs. 1, 2, and 3.

The lens is an achromatic meniscus, or concavo-convex, 3½ inches in diameter, 25 inches principal focal length, with a rack and pinion for adjusting the focus.

The stand on which the camera is supported is of simple construction. It is necessary that it should possess the means of giving to the camera a motion through small arcs of altitude and azimuth, and a sliding rectilineal motion in a direction at right angles to the optical axis of the lens. The construction is such as to admit of these movements. (See Figs. 1, 2, and 3.)

The top of the stand consists of two separate portions; the lower, a strong board working on a transverse axis, which rests on the frame of the stand, and is clamped at any required altitude by four screws, biting four hinged plates, which

connect the top of the stand with the frame. The amount of motion is regulated by an elevating screw.

The upper board on which the camera is placed is connected

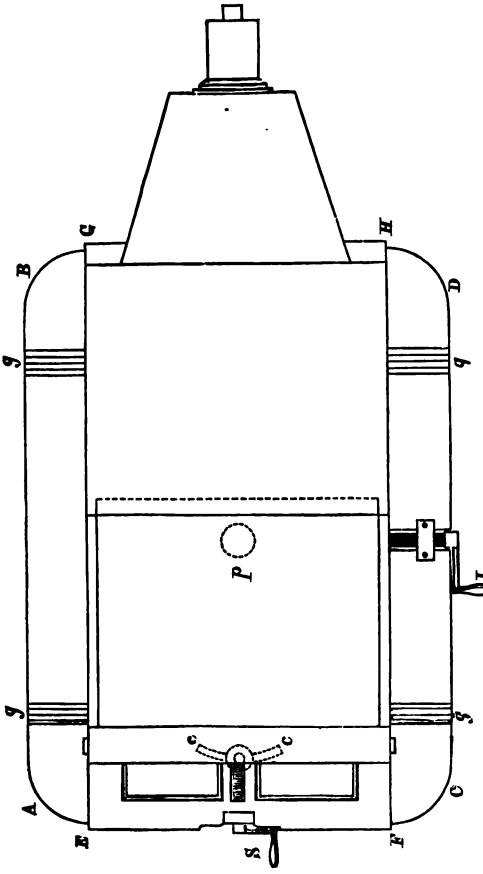


Fig. 1.—Plan of camera and stand. (Scale, 1 inch to a foot.)

with the lower one by a central pin, which passes through the top, and works in a socket in the lower board. (See Fig. 2.) Through the latter an arc of a circle is cut, and a screw

passing upwards through the arc, and fastened to the lower surface of the upper board, gives the means of clamping the top board in any portion of the azimuthal arc it describes on

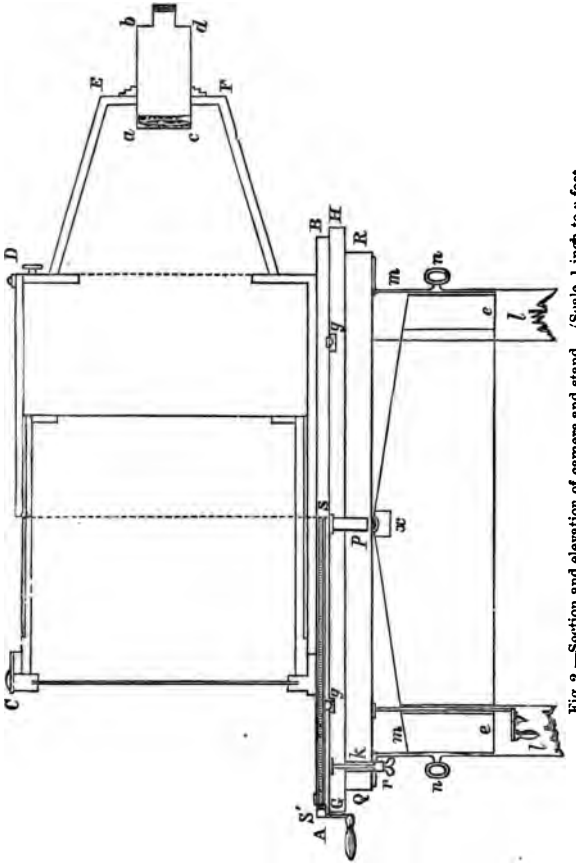


Fig. 2.—Section and elevation of camera and stand. (Scale, 1 inch to a foot.)

the centre pin, its motion being of course limited by the length of the arc cut in the lower board.

V-shaped grooved plates of brass are let transversely into the top surface of the stand, and to the bottom of the camera

are screwed similarly shaped brass runners; so that when the runners are fitted into the grooves, the camera lies symmetrically on the stand, and can be made to slide with an easy motion in a transverse direction, the motion being given by a

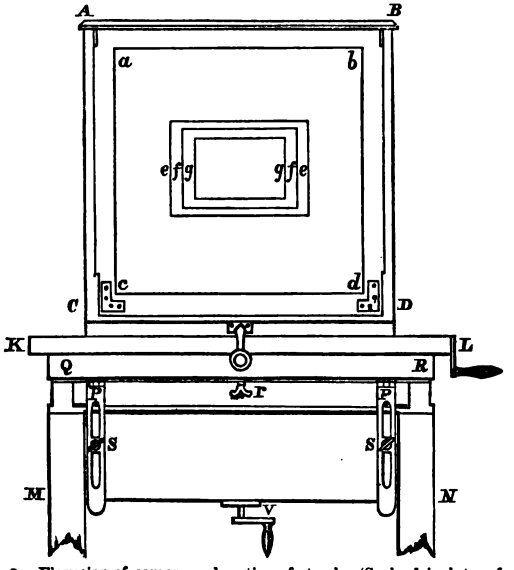


Fig. 3.—Elevation of camera and portion of stand. (Scale, 1 inch to a foot.)

male screw likewise let into the surface of the stand, and working in a small female-screw socket attached to the bottom of the camera.

Each of the legs of the stand has a groove at the bottom, to fit the convex surface of the rails on which it slides.

EXPLANATION OF THE PRECEDING FIGURES.

Fig. 1.

A B C D Top of camera stand.
E F G H Camera.
g g g g Brass **V** grooves.
p Centre pin, on which top of stand turns.
c c Circular groove through lower portion of stand.
L Screw for giving lateral motion to camera.

Fig. 2.

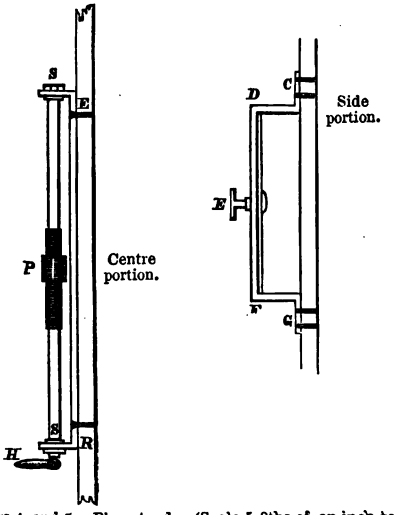
A B C D E F The camera.
G H Q R Top of stand.

G H Upper board.
a b c d Lens and mounting.
g g V shaped runners, working in V grooves.
k Circular arc cut through lower board.
l l Portion of legs of stand.
m m Hinged plates.
n n Screws for clamping plates.
p Centre pin, on which upper board works.
r Screw passing through circular arc, clamping upper to lower board.
s s Endless screw for focussing.
v Elevating screw for giving top of stand motion on axis *x*.
x Axis of top of stand.

Fig. 3.

A B C D Movable slide.
a b c d Ground glass plate.
e f g Rectangles ruled on glass, and to be made to coincide with margin line of plan according to nature of reduction.
K L M N Stand for camera.
P P Plates to allow motion in altitude.
s s Clamping screws for do.
Q R Lower board.
r Screw passing through circular arc, clamping upper to lower board.
v Screw for giving top of stand motion in altitude on axis.

The stand on which the plan-board is fixed is shown in Figs 4, 5, 6, 7, and 8.



Figs 4. and 5.—Plan stand. (Scale 5-8ths of an inch to a foot.)

It consists of a centre and two side pieces. The centre

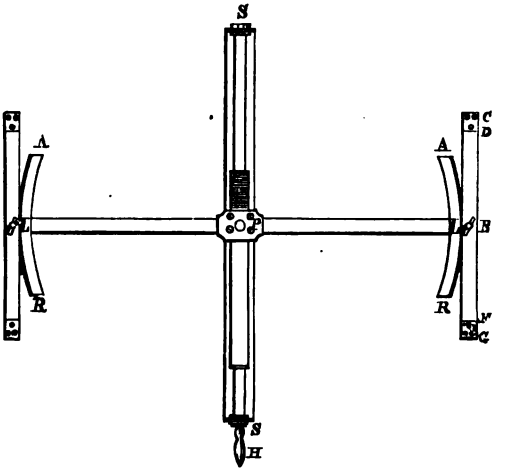


Fig. 6.—Plan-stand. (Front view. Board removed.)

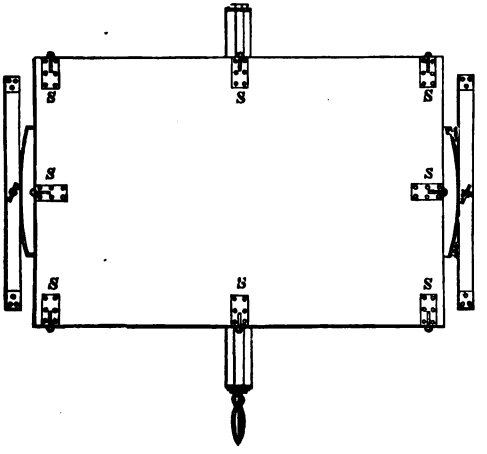


Fig. 7.—Plan-stand and board. (Front view.)

portion, Fig. 4, is composed of a frame, E R, screwed to the

partition with projecting sockets, in which the screw S S, works, turned by the handle H. A centre pin, P, is attached

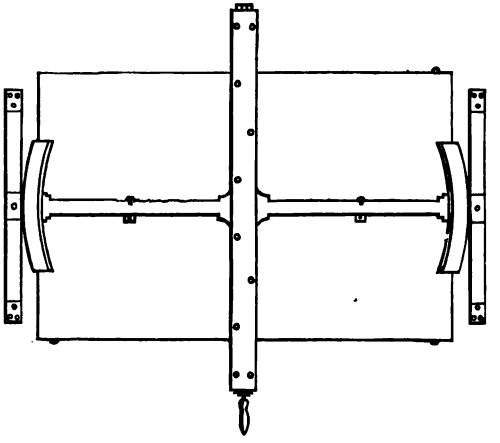


Fig. 8.—Plan-stand and board. (Back view. Partition removed. Scale, $\frac{1}{8}$ of an inch to a foot.)

to the screw S S, by a female-screw socket. A transverse bar, L L, Fig. 6, is connected with the screw by this pin, on which it revolves; and at the extremity of the bar are two arcs of circles, thinned at the outer edge.

Each of the side portions consists of a bent iron frame, C D F G, Fig. 5, screwed to the partition at C and G. The portion D F of the frame is double; the interior thin piece is pinned to the exterior only at the ends, and can, by reason of its flexibility, be separated at the centre by relaxing the screw E.

The thinned portion of the circular arcs A R, Fig. 6, being, when the stand is set up, between the exterior and interior piece of the side-frames, the arm L L can be clamped in any part of the arc it describes on the pin P, within a certain limit, by tightening the screw E.

Figs. 7 and 8 show the front and the back of the stand, with the plan-board attached.

The board, Fig. 7, is provided with spring catches, s, by which the plans are attached to the board.

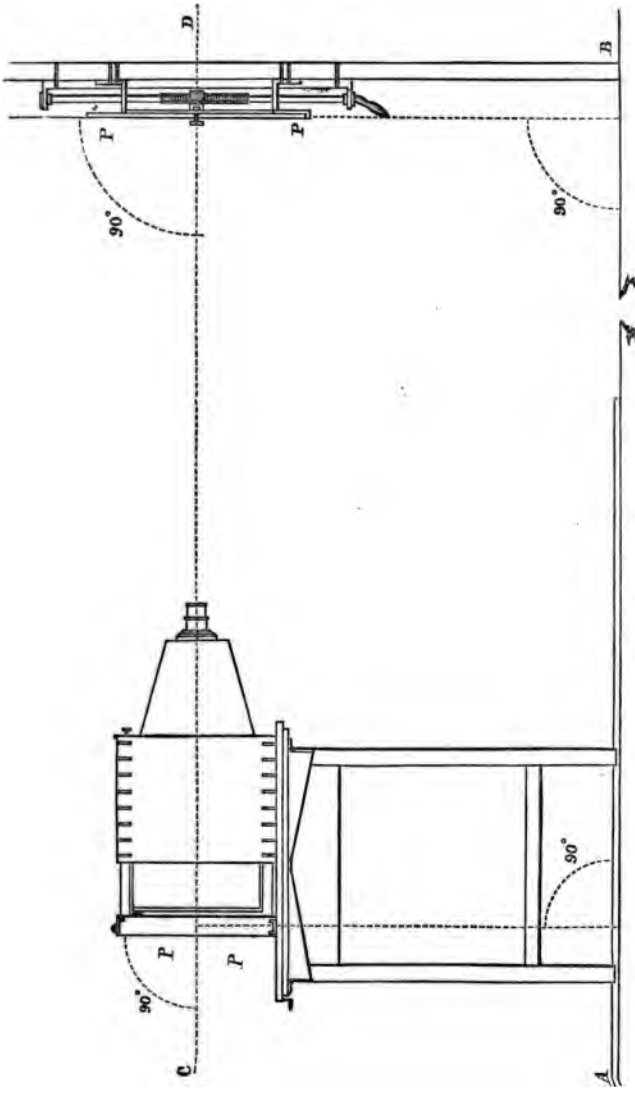
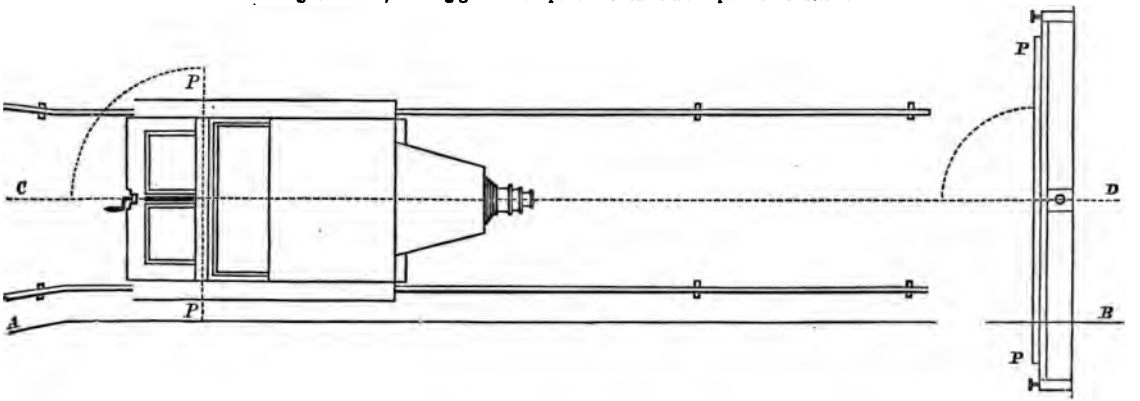


Fig. 9. Sectional Elevation on A B.

Fig. 10.—Plan, showing geometrical position of camera and plan for reduction.



EXPLANATION OF FIGS 9 AND 10.

C D Line in plane of adjustment, passing through centre pin of Plan Stand, centre of sensitive plate in camera, and coinciding with optical axis of lens.

P P Position of plan on board.

p p Position of sensitive plate in camera.

The theoretical conditions that must be satisfied to reduce correctly to a given scale are, that the centre of the sensitive plate and the centre of the plan be in the optical axis of the lens, that the surface of the sensitive plate should be parallel to the surface of the plan, and in the plane of the image, and that the marginal lines of the image of the plan must coincide with the rectangle ruled on the ground glass, representing the rectangle the plan should occupy when reduced to the given scale.

Figs. 9 and 10 give a sectional elevation and general plan, showing the arrangements made to enable these conditions to be satisfied.

The necessary adjustments are made partly with the camera and its stand, and partly with the stand on which the plan is fixed.

The plan to be reduced is fastened to the board by the catches, and the arm of the stand is turned till it is as nearly horizontal as can be judged.

The photographer, looking on the ground-glass plate, draws the camera-stand backward or forward, till the image of the plan appears nearly to fit the rectangle ruled on the glass, at the same time bringing the glass into the plane of the image as it advances to or recedes from the lens.

The centre of the image of the plan (previously marked on the plan) is now made to coincide with the centre of the rectangle ruled on the glass, by moving the plan in a vertical direction by means of the screw of the plan-stand, and by moving the camera in a horizontal direction on the runners.

The parallelism of the surface of the plan and the ground glass will be indicated by the symmetrical position of the margin lines of the image and of the sides of the rectangle on the glass; or, in other words, when the centres coincide, if the surfaces are parallel, the margin of the image will either coincide with the margin of the rectangle on the ground glass, or it will be equally distant from it on every side, and conversely if the surfaces are *not* parallel.

The rails having been placed carefully at right angles to the surface of the plan and levelled, and the plan-stand being as nearly as possible vertical, the degree of inclination of the surfaces to each other will be very slight, and such as can easily be adjusted by the motions provided for the camera-stand.

A little consideration will enable the operator to judge of

and apply the movement required to produce parallelism, from the position already referred to, of the margin of the plan image relative to the margin of the rectangle on the glass. It has been already stated that a want of parallelism will be indicated by the margins not being at equal distances on all sides; and it follows from this that the mark representing the centre of the plan seen in the image will not be in the centre of the rectangular image. From the position of the margin with reference to the centre can be deduced the relative position of the surfaces of the plan and ground glass.

Fig. 11, is supposed to be either a plan or section of the two surfaces: G R being the surface of the ground glass;

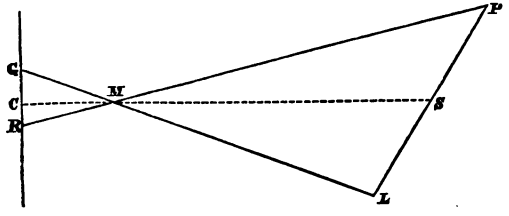


Fig. 11.

M the lens, the optical axis of which (C M) is at right angles to the surface, G R, and P L, the plan; S the centre of the plan, and C the centre of the rectangle, ruled on the ground glass; G R will be the image of the plan thrown on the glass, G and R being in the centre of opposite sides of the image.

Now it is evident, on inspection of the diagram, that when R P is greater than G L, G C is greater than C R; that is, the edge of the plan at P being farther, than the edge at L, from the lens M, the image of P at R, is nearer the centre of the ground glass, than the image of L at G.

By reasoning in this way, it will be at once suggested to the operator what movement in altitude or azimuth is to be given to the camera, to produce parallelism.

This movement will throw the centres of the plan-image and ground glass off each other; they are made again to coincide as before, and thus, by repeated adjustment, coincidence of the centres and parallelism of the surfaces are ensured.

It then only remains to produce coincidence of the sides of the rectangles by the rack-and-pinion motion of the lens and the screw for focusing the camera.

The adjustment is now complete, and it is only necessary to remove the focusing-glass, and to slip the sensitive plate into the same place, to receive a correct reduced image.

The time taken in this adjustment is about four minutes in the first instance, and one minute afterwards for each change of plan, provided the ratio of the reduction is the same.

THE PHOTOGRAPHIC PROCESS USED FOR THE PRODUCTION OF REDUCED COPIES.

The process used for the reduction of plans is that known by the name of the "wet collodion" process.

A general description of the different operations is all that is considered necessary in these memoranda. Detailed and minute directions in manipulating, as well as a complete synopsis of the chemistry of the subject, are given in Mr. Hardwick's "Manual of Photography."*

The operations for the production of the "negative" are—

1. The cleaning of the glass plate.
2. Coating the plate with collodion.
3. Immersion of plate in nitrate-of-silver bath, or sensitising plate.
4. Exposure of sensitive plate in camera.
5. Development of image on plate.
6. Fixing negative plate.
7. Intensifying negative, including immersion in solution of bichloride of mercury and washing with hydrosulphate of ammonia.
8. Varnishing negative.

1. *Cleaning the Glass Plates.*—The cleaning of the glasses used for photography is a point of considerable importance, and of more difficulty than would at first sight appear.

The delicacy of the chemical changes which unite in producing the negative is so great, that a very slight impurity in

* Also in Mr. Thornthwaite's adaptation of Professor Von Monckhoven's "Traité Populaire de Photographie sur Collodion," Weale *Series, No. 79.*

the surface of the glass has an effect in controlling or influencing them; and there is a special difficulty in the present case from the effect produced on the glass by the bichloride of mercury used in process No. 7. This effect appears to be caused by the affinity of the mercury for the lead used in the manufacture of the glass. The consequence is a combination of the two, and the mercury becomes, as it were, a part of the glass. Unfortunately, it only remains combined with the lead till it is brought into contact with iodide of silver in the sensitive film; it then appears to decompose that salt, combining with the iodine, and rendering the film insensitive at those points where it existed previous to the immersion of the plate in the silver bath. The effect produced is that of a number of transparent spots on the negative.

In order, therefore, to render glass which has been once used again fit for photographic purposes, it is boiled in water for three or four hours, when the greater portion of the mercury passes off with the steam; it is then immersed in a dilute solution of iodine, in order that the iodine may form a more stable compound with it. The glass plate is then rubbed with Tripoli powder and ammonia, and placed in a holder (to avoid contact with the hand), dried, and polished with chamois leather. It is then ready for use; but, after all, when a little additional expense is no objection, it is better to use glass plates not more than twice, if they go through the intensifying process.

2. *Coating the Plate with Collodion.*—The plate, held in a pneumatic holder, receives a small quantity of collodion, such that a slight inclination of the plate may cause it to run over the whole surface, it is then drained off, and the evaporation of the ether leaves a thin film on the glass.

A full description of the mode of preparing collodion is given in Mr. Hardwick's "Manual of Photography," already referred to.*

3. *Immersion of the Plate in the Nitrate-of-silver Bath.*—The formulæ of the various solutions used, including that of the nitrate bath, are given page 130. The characteristics of a good negative are—

1st. Clearness of the detail of the plan photographed.

2nd. Intensity of the ground of the negative.

The condition of the bath which is calculated to produce

* Also in Mr. Thornthwaite's adaptation, &c., p. 20.

the best negatives may be defined to be such that the slightest decrease in quantity of the acid present will produce fogging in the detail of the negative.

The plate, when coated with the iodized collodion, is immersed in the bath for about five minutes, removed, drained, and placed in the ordinary dark slide.

4. *Exposure of the Plate.*—The time of exposure varies continually. The principal cause of the variation is the quantity, intensity, and actinic force of the light entering the lens; and the range is from eight minutes to twenty-five seconds.

When the means employed to estimate the proper exposure are the eye and a watch, the variations are so rapid, and the plate so sensitive to them, that on some days forty per cent. of the negatives may either be under or over exposed. These failures have been almost entirely obviated by the use of sensitive paper as a photometer. The following is the *modus operandi*:—

The paper is prepared as for "printing;" a box about 9 inches long, 2½ in. broad, and ¼ in. deep, is divided by sixty interior partitions placed transversely across. Each of the portions thus made is closed by a sliding lid. This box is then hung up by the side of the plan-board, and in each compartment of the box is placed a slip of sensitive paper, the lids being then closed. At the instant the negative is exposed by the removal of the stop of the lens, one of the lids of the box is removed so as to uncover one of the slips of paper. When the paper acquires that shade, which we know from previous experience indicates the time at which the plate has been sufficiently exposed, the cap is placed on the lens, and the lid is closed on the box containing the sensitive paper.

If the negative appears to have been under-exposed (and the mistake may occur with the first negative taken on any day), the stop is not placed on the lens the next time, till the paper has received a slightly darker shade. While the next exposure is going on, the slip of paper first coloured is uncovered from time to time, in order that the eye may compare the tint with the new one now in use. If the negative first taken is found to have been rather over-exposed, the exposure is stopped before the second slip of paper has attained so dark a tint; and, finally, if the development shows that the negative received the proper amount of exposure, the exposure of

each negative subsequently taken is stopped when the paper has attained that shade.

Clearness of detail in the negative is the first essential, and the time of exposure must be regulated so as most perfectly to produce this result.

5. *Development of the Negative.*—When the plate has been exposed, it is carried to the dark room, and a portion of the developing solution poured on it sufficient to cover it. The fluid is kept in motion over the surface of the plate; and if there is any appearance of undue exposure, a small quantity of nitrate of silver is added.

The amount of development is, like the exposure, regulated by the essential condition of clearness of detail, and is carried to the utmost extent compatible with that. In cold weather it is advantageous to warm the developing solution.

6. *Fixing the Negative.*—The negative, when sufficiently developed, is washed with water, and fixed with cyanide of potassium.

If the previous operations have been well performed, the process of fixing will dissolve from the detail every portion of the iodide of silver, and leave the lines perfectly clear. After fixing, the negative is washed with water.

The following general remarks apply to the above processes:—

It is found that when the plan is perfectly clean (as in the case of a new copper-plate impression), and the bath in good order, a negative can be produced (by development with pyrogallic acid alone), in good light, so dense in the ground, and clear in the detail, that the resulting print shall be only a slight shade darker in the ground than the paper of the impression, while the detail shall be jet black. If there is a failure in any of these conditions, viz., in the cleanliness of the plan, in the light, or in the bath, there is a perceptible difference in the prints.

7. *Intensifying the Negatives.*—The plans reduced are, for the most part, manuscripts, and pass through many hands. They are all considerably soiled in consequence, and thus one of the conditions for producing perfect impressions is wanting. It is found necessary, therefore, to intensify the negatives of MS. plans after they have been fixed. For this purpose, the negative is immersed in a saturated solution of bichloride of mercury (corrosive sublimate) till it is thoroughly whitened; it is then removed, and washed with water. A dilute solution

of hydrosulphate of ammonia, ten of water to one, is poured over the plate, so as to flow over the whole surface.

The ground of the negative is in this way converted into a sulphuret of silver and mercury, and the film is of a brown-yellow colour, and in great measure impervious to chemical rays.

It is impossible to produce good prints unless the negatives of the MS. plans are treated in this way.

8. *Varnishing the Negative.*—When dry, the negative is varnished with a solution of gum mastic in benzine. This varnish is only one-third the cost of the best (amber in chloroform) kind, but answers very well when negatives are not to be kept for any length of time. For work required to be preserved, the latter kind is used.

The operations for the production of the print, or positive, are—

1. Salting and albumenizing the paper,
2. Making the paper sensitive,
3. Printing,
4. Fixing and toning,
5. Washing the prints.

1. *Salting and albumenizing.*—The paper is floated on the solution for one minute and a half, then removed and hung up to dry.

2. *Making the Paper sensitive.*—The paper is floated on a solution of nitrate of silver in water for five minutes and then removed and dried.

This process is carried on in a dark room.

3. *Printing.*—The negative is placed in a printing-frame, in contact with a piece of sensitive paper, and exposed to the light. The exposure is carried on until the detail is sufficiently clearly seen, allowing for the reducing power of the toning bath.

If the negative is a good one, the print will be of an intense chocolate-colour, whilst the ground of the print will be hardly tinged; and after toning, the ground will be white, and the print a jet black.

4. *Toning and fixing the Prints.*—The fixing and toning are carried on simultaneously, in a bath of hyposulphate of soda with chloride of gold.

The detail, as before observed, should in the toning bath become a jet black; and when this stage has been attained, the *print should be* removed. Experience is the best guide in

performing these operations: fixed rules can hardly be laid down for them; for if the printing is carried on for a considerable time, to bring out details which, having been in an unfavourable colour on the plan, have not photographed clearly, it will be at the expense of the general whiteness of the ground of the print. If, on the other hand, the printing is stopped early, in order to preserve the ground of the negative, it is probable that some of the details will not be sufficiently printed; and the same remarks apply to the toning.

Judgment must be exercised so as to carry each process to that extent from which the best general result will be secured.

5. *Washing the Prints.*—It is very important that the prints should be washed so thoroughly as to leave in the paper no trace of the hyposulphite of soda. A very minute portion of this salt is sufficient to cause the print to fade in a short time.

The prints are placed in a trough of water, through which a stream is constantly running from two pipes (see Figs, 13 and 14.) The mouth of one of the pipes is at the bottom

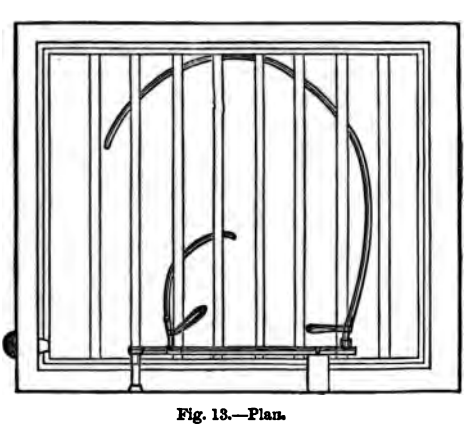


Fig. 13.—Plan.

of the trough, and that of the other halfway between the bottom and the top. Both pipes are curved, so that a rotatory motion is given to the whole body of water. A waste pipe at the top, and another at the bottom, carry off the

surplus water as fast as it flows in. The prints are left in the water-trough from six to eight hours.

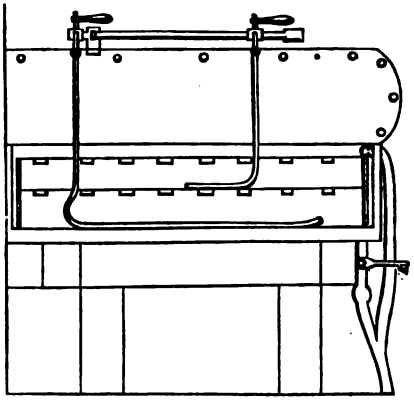


Fig. 14.—Section.

In order that the prints may be dispersed throughout the body of water in the trough, instead of floating at the top, the trough is divided horizontally into three compartments, by movable wooden trays; as soon as a certain number of prints have been placed in the trough, one of the trays is placed on top of them, and the whole are forced down to the lowest compartment in the trough. The next supply is treated in the same manner with the second tray, and the remainder are allowed to float on the top. The trays are made of battens nailed to a wooden frame at intervals of an inch apart, and the frame is loaded with lead.

FORMULÆ OF THE SOLUTIONS USED IN PHOTOGRAPHY.

Nitrate Baths for Collodion Negatives.

Nitrate of silver	1 ounce
Distilled water	2 ounces, dissolve
Iodide of potassium	3 grains
Distilled water	1 drachm, dissolve.

Mix these two solutions, the precipitate (iodide of silver) thus formed is by shaking entirely dissolved.

Now add fourteen ounces of distilled water, when the excess of iodide of silver is again thrown down, but in such a finely divided state as to render the saturation of the bath with iodide of silver perfect.

After half an hour, add alcohol 2 drachms, sulphuric ether 1 drachm, and then filter.

Developing Solution for Negatives.

Pyrogallic acid	20 grains
Glacial acetic acid	1 ounce
Alcohol	6 drachms
Distilled water	20 ounces.

Dissolve the pyrogallic acid in water, and then add the acetic acid and alcohol.

Fixing Solution.

Cyanide of potassium	15 grains
Distilled water	1 ounce, dissolve.

Solution for intensifying Negatives

Bichloride of mercury	30 grains
Distilled water	1 ounce (or saturated solution)
Hydrosulphuret of ammonia	1 „
Water	5 ounces.

Immerse the negative in the solution of bichloride of mercury until it has become well whitened; wash with water, and then pour quickly over the plate the dilute hydrosulphuret of ammonia, and again well wash with water.

Albumen and Salting Solution of Paper.

White of six eggs	
Distilled water	6 ounces
Chloride of ammonium	3 drachms.

When the ingredients are mixed, take a bundle of quills or a fork, and beat the whole into a perfect froth. As the

froth forms, it is to be skimmed off and placed in a flat dish to subside. When the froth partially subsides, transfer it to a tall and narrow jar, and allow it to stand for several hours, that the membranous shreds may settle to the bottom; then pour off the upper clean portion, which is fit for use.

Nitrate Bath for Paper.

Nitrate of silver	1 ounce
Distilled water	7 ounces.

Fixing and Toning Bath.

Chloride of gold	8 grains
Nitrate of silver	16 „
Hyposulphite of soda	4 ounces
Water	8 „

Dissolve the hyposulphite of soda in four ounces of water, the chloride of gold in three ounces, and the nitrate of silver in the remaining ounce; then pour the diluted chloride by degrees into the hyposulphite, stirring with a glass rod, and afterwards the nitrate of silver in the same way.

CHAPTER IX.

INSTRUMENTS FOR MEASURING THE ANGLES OF CRYSTALS.

THE GONIOMETER.

This instrument is used for measuring the angles of crystals. The following description of the construction and method of using this instrument is extracted from the able article on Crystallography, in the "Encyclopædia Metropolitana:"—

"The instruments used for measuring the angles at which the planes of crystal incline to each other are called goniometers.

"The mutual inclination of any two planes, as of *a* and *b*,

Fig. 1, is indicated by the angle formed by two lines, *e d*, *e f*, drawn upon them from any point, *e*, on the edge at which they meet, and perpendicular to that edge.

"Now it is known that if two right lines, as *g f*, *d h*, Fig. 2, cross each other at any point, *e*, the opposite angles *d e f*, *g e h*, are equal. If, therefore, the lines, *g f*, *d h*, are supposed to be very thin and narrow plates, and to be attached together

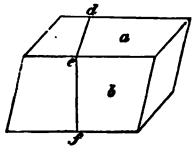


Fig. 1.

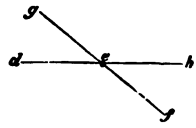


Fig. 2.

by a pin at *e*, serving as an axis to permit the point, *f*, to be brought nearer either to *d* or to *h*, and that the edges, *e d*, *e f*, of those plates are applied to the planes of the crystal, Fig. 1, so as to rest upon the lines, *e d*, *e f*, it is obvious that the angle, *g e h*, of the movable plates would be exactly equal to the angle, *d e f*, of the crystal.

"The common goniometer is a small instrument for measuring this angle, *g e h*, of the movable plates. It consists of a semicircle, Fig. 3, divided into 360 equal parts, or half degrees, and a pair of movable arms, *d h*, *g f*, Fig. 4, the semi-

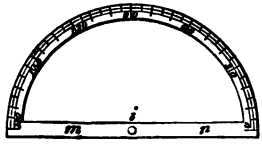


Fig. 3.

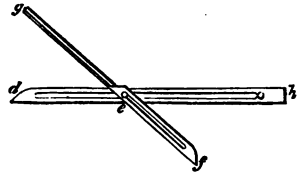


Fig. 4.

circle having a pin at *i*, which fits into a hole in the movable arms at *e*.

'The method of using this instrument is to apply the edges, *d e*, *e f*, of the movable arms to the two adjacent planes of any crystal, so that they shall actually touch or

rest upon those planes in directions perpendicular to their edge. The arm, *d h*, is then to be laid on the plate, *m n*, of the semicircle, Fig. 3, the hole at *e* being suffered to drop on the pin at *i*, and the edge nearest to *h* of the arm will then indicate on the semicircle, as in Fig. 5, the number of degrees which the measured angle contains.

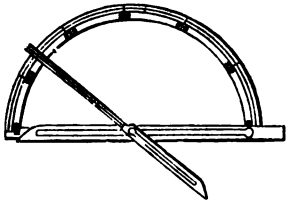


Fig. 5.

"When this instrument is applied to the planes of a crystal, the points, *d* and *f*, Fig. 4, should be previously brought sufficiently near together for the edges, *d e*, *e f*, to form a more acute angle than that about to be measured. The edges being then gently pressed upon the crystal, the points, *d* and *f*, will be gradually separated, until the edges coincide so accurately with the planes that no light can be perceived between them.

"The common goniometer is, however, incapable of affording very precise results, owing to the occasional imperfection of the planes of crystals, their frequent minuteness, and the difficulty of applying the instrument with the requisite degree of precision.

"The more perfect instrument, and one of the highest value to crystallography, is the reflecting goniometer, invented by Dr. Wollaston, which will give the inclination of planes whose area is less than $\frac{1}{100000}$ of an inch, to less than a minute of a degree.

"This instrument has been less resorted to than might, from its importance to the science, have been expected, owing, perhaps, to an opinion of its use being attended with some difficulty. But the observance of simple rules will render its application easy.

"The principle of the instrument may be thus explained:—

"Let *a b*, Fig. 6, represent a crystal, of which one plane only is visible in the figure, attached to a circle, graduated on its edge, and movable on its axis at *o*; and let *a* and *b* mark the position of the two planes whose mutual inclination is required.

"And let the lines, *o e*, *o g*, represent imaginary lines, resting on those planes in direction perpendicular to their common edge, and the dots at *i* and *h* some permament marks in a line with the centre, *o*.

"Let the circle be in such a position that the line, *o e*, would pass through the dot at *h*, if extended in that direction, as in Fig. 6.

"If the circle now be turned round with its attached

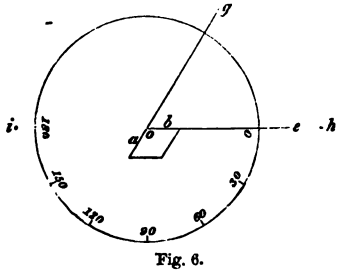


Fig. 6.

crystal, as in Fig. 7, until the imaginary line, *o g*, is brought into the position of the line, *o e*, in Fig. 6, the number 120 will stand opposite the dot at *i*. This is the number of degrees at which the planes *a* and *b* incline to each other. For if the line *o g* be extended in the direction *o i*, as in Fig. 7, it is obvious that the lines, *o e*, *o i*, which are perpendicular to the common edge of the planes, *a* and *b*, would intercept exactly 120° of the circle.

"Hence an instrument constructed upon the principle of these diagrams is capable of giving with accuracy the mutual inclination of any two planes which reflect objects with

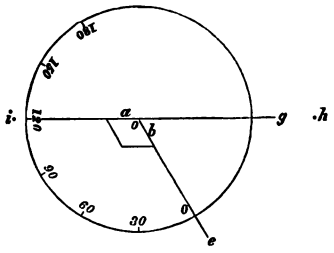


Fig. 7.

sufficient distinctness, if the means can be found for placing them successively in the relative positions shown in the two preceding figures.

"This purpose is effected by causing an object, as the line at *m*, Fig. 8, to be reflected successively from the two planes, *a* and *b*, at the same angle. It is well known that the images of objects are reflected from bright planes at the same angle

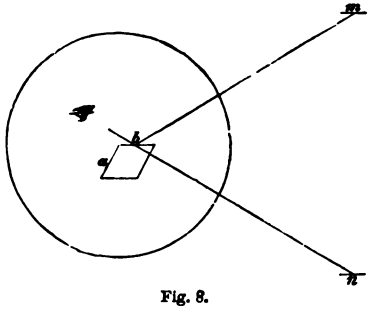


Fig. 8.

as that at which their rays fall on those planes; and that when the image of an object reflected from a horizontal plane is observed, it appears so much below the reflecting surface as the object itself is above.

"If, therefore, the planes *a* and *b*, Fig. 8, are successively brought into such positions as will cause the reflection of the line at *m*, from each plane, to appear to coincide with another line at *n*, both planes will be successively placed in the relative positions of the corresponding planes in Figs. 6 and 7.

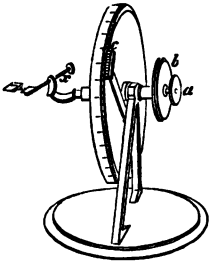


Fig. 9.

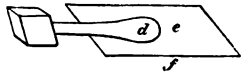


Fig. 10.

To bring the planes of any crystal successively into these relative positions, the following directions will be found useful.

"The instrument, as shown in the sketch, Fig. 9, should *be first placed on* a pyramidal stand and the stand on a

small steady table, about 6 or 10 or 12 feet from a flat window. The graduated circular plate should stand perpendicularly from the window, the pin *x* being horizontal, not in the direction of the axis, as it is usually figured, but with the slit end nearest to the eye.

"Place the crystal which is to be measured on the table, resting on one of the two planes whose inclination is required, and with the edge at which those planes meet nearest and parallel to the window.

"Attach a portion of wax, about the size of *d*, to one side of a small brass plate, *e*, Fig. 10; lay the plate on the table with the edge, *f*, parallel to the window, the side to which the wax is attached being uppermost, and press the end of the wax against the crystal until it adheres; then lift the plate with its attached crystal, and place it in the slit of the pin, *x*, with that side uppermost which rested on the table.

"Bring the eye now so near the crystal, as, without perceiving the crystal itself, to permit the images of objects reflected from its planes to be distinctly observed, and raise or lower that end of the pin, *x*, which has the small circular plate on it, until one of the horizontal upper bars of the window is seen reflected from the upper or first plane of the crystal, corresponding with the plane *a*, Fig. 6, and until the image of the bar appears to touch some line below the window, as the edge of the skirting-board where it joins the floor.

"Turn the pin, *x*, on its own axis also, if necessary, until the reflected image of the bar of the window coincides accurately with the observed line below the window.

"Turn now the small circular handle, *a*, on its axis, until the same bar of the window appears reflected from the second plane of the crystal corresponding with plane *b*, Figs. 6 and 7, and until it appears to touch the line below; and having, in adjusting the *first* plane, turned the pin, *x*, *on its axis*, to bring the reflected image of the bar of the window to coincide with the line below, *now move the lower end of the pin laterally*, either towards or from the instrument, in order to make the image of the same bar, reflected from the second plane, coincide with the same line below.

"Having ascertained by repeatedly looking at, and adjusting both planes, that the image of the horizontal bar, reflected successively from each plane, coincides with the observed lower line, the crystal may be considered ready for measurement.

"Let the 180° on the graduated circle be now brought opposite the 0 of the vernier at *c*, by turning the handle *b*; and while the circle is retained accurately in this position, bring the reflected image of the bar from the *first* plane, to coincide with the line below, by turning the *small* circular handle *a*. Now turn the graduated circle, by means of the handle *b*, until the image of the bar, reflected from the *second* plane, is also observed to coincide with the same line below. In this state of the instrument the vernier at *c* will indicate the degrees and minutes at which the two planes are inclined to each other.

"The accuracy of the measurements taken with this instrument will depend upon the precision with which the image of the bar, reflected successively from both planes, is made to appear to coincide with the same line below; and also upon the 0, or the 180°, on the graduated circle, being made to stand precisely even with the lower line of the vernier, when the first plane of the crystal is adjusted for measurement. A wire being placed horizontally between two upper bars of the window, and a black line of the same thickness being drawn parallel to it below the window, will contribute to the exactness of the measurement by being used instead of the bar of the window and any other line.

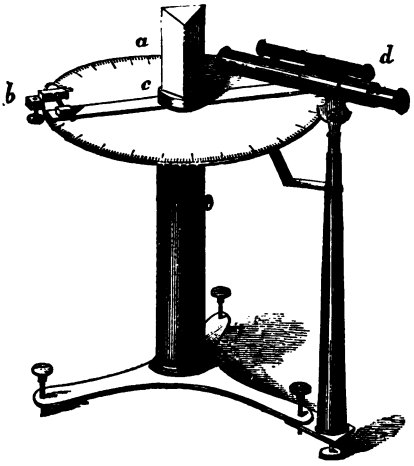
"Persons beginning to use this instrument are recommended to apply it first to the measurement of fragments at least as large as that represented in Fig. 10, and of some substance whose planes are bright. Crystals of carbonate of lime will supply good fragments for this purpose, if they are merely broken by a slight blow of a small hammer.

"For accurate measurement, however, the fragments ought not, when the planes are bright, to exceed the size of that shown in Fig. 9, and they ought to be so placed on the instrument, that a line passing through its axis should also pass through the centre of the small minute fragment which is to be measured. This position on the instrument ought also to be attended to when the fragments of crystal are large. In which case the common edge of the two planes, whose inclination is required, should be brought very nearly to coincide with the axis of the goniometer; and it is frequently useful to blacken the whole of the planes to be measured, except a narrow stripe on each close to the edge over which the measurement is to be taken."

Wollaston's goniometer has been somewhat modified and

improved by the French optician, Charles, whose construction we proceed to describe.

This instrument consists of a graduated brass circle, *a*, supported by, and turning on, an axial pillar at right angles to its plane: this pillar rises from a tripod, standing on three screws, which serve to set the circle horizontal. An index-bar turns on a pivot at the centre of the circle, and over the pivot is a capstan-head, on which is fixed with *soft* wax the crystal whose angles are to be measured. The extremity of the index-bar carries a vernier, and has a clamp and tangent screw for setting it accurately.



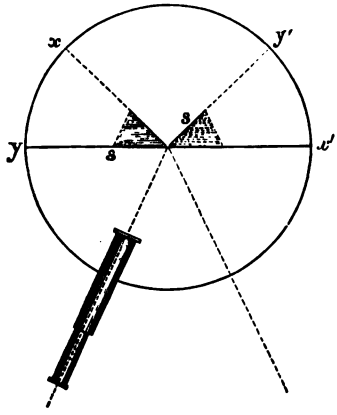
From one of the corners of the tripod rises a tube supporting a telescope, *d*, that has a motion in a horizontal, and also one in a vertical, plane.

The circle having first been adjusted for horizontality, it only remains to place the edge of the crystal, that forms the vertex of the dihedral * angle to be measured, vertical, and consequently parallel to the axis of rotation of the index-bar, without being too far from the centre of motion, the amount of eccentricity permissible depending upon the extent of the faces of the angle to be measured, as it is only necessary that

* *Dihedral angle*, angle between two plane surfaces.

the fixed axis of the telescope should always be directed to some point within the boundaries of these faces.

Adjustments.—At the focus of the telescope are placed several parallel and vertical cobweb threads, with means for adjusting their exact verticality: the telescope being directed to a distant vertical line, such as a lightning conductor, or the corner of a building, one of the micrometric threads must be brought into coincidence with this line: the telescope is then to be turned round, and directed towards the crystal, and the image of the same line is to be observed, reflected first from one of the faces of the dihedral angle, and then from the other: the inclination of the image can be varied by moving the crystal on the soft wax; and, when, after some trials, the reflected image, passed in succession across



the field of view by turning the index-bar, fall exactly on the micrometric lines, the two faces of the dihedral angle will be both vertical, and so also will be its edge.

When this adjustment is perfected, the index of the vernier is to be brought to the zero division of the circle *a*, and the circle and index-bar are to be turned round together, until the image of the line reflected from one of the faces of the angle, falls exactly on the central micrometric thread; the circle is then to be fixed by the clamping screw, and the index-bar only to be turned, until the image reflected from

the other face falls on the same thread; and the angle through which it has been necessary to move the index-bar is *the supplement* of the angle required. If, for instance, the first reflection has proceeded from the face $s\,y$, the second reflection from the face $s\,x$ will fall on the central micrometric thread, when this face has come into the position $s\,x'$, and consequently when it has described the angle $x\,s\,x'$, the supplement of the required angle $y\,s\,x$.

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